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SAFETY ANALYSIS OF THE 8-INCH LOW-PRESSURE HELIUM HEADER SYSTEM FOR THE ENERGY SAVER

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Abstract

The 8" diameter low-pressure helium recollection header system of the Energy Saver is analyzed to determine a safe upper limit for the pressure which it can tolerate during quenches without rupturing or breaking anchors. This system begins with the Kautzky relief valves which vent helium from each magnet into the 8" header and ends with the 6 psi relief valves on the header itself on top of each refrigerator building. All components of the system which are stressed during a quench are individually analyzed. The analysis includes both engineering calculations and empirical destructive testing performed when calculations were not viable. The conclusion is that the system can tolerate pulsed pressures of 100 psig, with safety factors varying between 2 and 4. A failure-mode analysis of the Kautzky relief valve is also included.

I. Introduction

The 8" helium header is part of the satellite refrigerator gas piping system. The header serves as the suction return line for the compressors as well as the main magnet relief exhaust line and cooldown flow-collection line. This 8" diameter, Schedule 5, 304 stainless steel pipe is located in the tunnel adjacent to the Main Ring magnets and is continuous around the circumference of the ring.

The 8" header leaves the tunnel only at the 24 refrigerator buildings (feedcan regions) and at the six compressor buildings (straight section regions). In the tunnel, the header has expansion joints (hydroformed bellows) every 200 feet and two in-line isolation valves between each of the 24 cryoloops (see Fig. 1). The primary relief valves for the system are 8" diameter spring-loaded, paralled-plate relief valves on top of each refrigerator building set to crack at 6 psig and similar valves at each compressor building which crack at 12 psig. These valves vent outdoors. Secondary relief is provided by a pair of 4" diameter spring-loaded, parallel-plate relief valves in the tunnel at each of the 18 double-turnaround (DTA) regions set to crack at 50 psig. These valves are expected to vent to the tunnel only during an exceptionally global quench or in the event of the failure of one of the outdoor relief valves.

II. Operating Modes

The three different operating modes of the 8" header system impart a variety of design considerations on the system. As a low pressure suction line, the header must be capable of moving gas with minimal pressure drop. This mode of the system need not be discussed as it has no impact on safety.

The magnet cooldown flow mode causes the maximum localized thermal contraction of the header. To accommodate this pipe contraction in the expansion joints without exceeding the recommended stroke, it was required that more than one expansion joint participate in the accommodation of a very local cold spot. This is achieved by anchoring the system only every 400 feet and mounting the pipe on rollers whose total resistance to motion is negligible compared with the expansion joint spring rate. Thus, three expansion joints share any thermal contraction by pulling sections of pipe along the rollers.

In the cooldown mode, the header also sees the phenomenon of pipe bow caused by stratified two-phase flow which creates a temperature gradient in the cross section of the pipe. Because of this bow, consideration has to be given to bracket strength and to the clearance between the flexhose and the Main Ring magnets.

The final mode of operation considered is that of the main magnet relief exhaust line, or quench relief mode. The Kautzky relief valves which are attached to each dipole and spoolpiece (1373 in number) vent into the 8" header through flexhose when magnets quench or are overpressured for some other reason. It is in this mode that the header sees the maximum pressure and maximum forces on anchors. Extrapolation of data gathered during full-sector quenches in A-Sector (see Appendices D and E) indicate that the peak header pressure will be 90 psig at 4440 amps (corresponding to a proton energy of 1 TeV). Some perspective on the level of hazard involved in the event of a massive rupture of the header is gained by noting that the stored energy of the header at the peak of a full-sector quench is 24 megajoules per sector.

Protection of the magnets from damage resulting from overpressurization during the full current quenches is a governing factor in the pressure limitations and relief valve pressure settings on the 8" header. The Kautzky valve relief pressure is set at 34 psig, a factor two above the normal operating pressure of the cryostat, but low enough that good flow is established before the peak pressure of the quench. The relief valves on the header above the refrigerator buildings are set to crack at 6 psig. This pressure is set to limit operational problems of valve reseating and gas inventory losses. The 12 psig relief setting of the relief valves at the compressor buildings is chosen to limit supercharging of the compressors during a quench.

The pressure drop in the vertical riser leading from the tunnel to the refrigerator building relief valves is sufficiently great that additional in-tunnel relief valves are necessary to protect both the header system and magnet cryostats against excessive pressures during a massive quench in which all the magnets in two adjacent cryoloops quench simultaneously. This fact was recognized when the header system was designed. Data taken at low currents in A-Sector before the in-tunnel relief valves were installed confirmed this fact. Two such valves are placed at each DTA region - half way between refrigerator buildings - with cracking pressure set to 50 psig. This pressure was set to be high enough that the relief valves would not open during any conceivable accident when people were present (such as a bore tube vacuum rupture - see comments below). In addition, these valves will open only rarely at times when people are not permitted to be present; i.e., when the Energy Saver magnets are energized. These in-tunnel relief valves do not open during single-cell or even full cryoloop quenches, but only when two adjacent cryoloops quench at a current higher than 2500 amps.

George Mulholland has thought through a variety of possible accidents which might lead to header pressures in excess of 50 psig when people are permitted to be present (see Appendix A). The worst case which he finds is a massive bore-tube vacuum rupture at the feedcan region of the cryoloop. Whether the header pressure would exceed 50 psig in this instance was deemed "too close to call."

III. Forces

Expansion joints are employed in the 8" header tunnel piping to adsorb contraction initiated by cold gas. At locations where the pipe axis changes direction, as at an elbow, the pipe needs to be anchored in order to protect the expansion joint against overextension. In the design of these anchor points, the forces which set on them must be determined. The thrust force generated by an internal pressure in an expansion joint is equal to the product of the pressure and the thrust area, which in our case is 62 in^2. Thus forces of this type have a maximum of 5600 lbs. given a peak header pressure of 90 psi.

The installation of the 8" header required that some expansion joints be preloaded or precompressed by one inch on installation in order to improve cycle life. This preloading requires a force equal to the product of the distance and the spring rate of the expansion joint, which is 450 lbs/in. The resulting 450 lb force is additive to the forces generated by the internal pipe pressure when used for anchor analysis.

Another force which acts on anchor points is the inertial force generated by a change in direction of the gas flow in the pipe. This phenomenon occurs at the 90° elbows in the feed-can area and at the medium and long straight section 12 inch radial offsets. The force can be calculated if the mass flow rate and density are known. These can be derived from the A-Sector quench pressure data with about 40% error bars (see Appendix A).

The magnitude of this force at the feedcan 90° elbows is 800 lbs in both the vertical and along-the-beam direction. This result is for the worst case of a full-current quench of two or more adjacent cryoloops.

The inertial force at the medium straight section offset is much less since both the flow rate and the gas temperature are lower at this point. The axial force which must be restrained is 280 lbs. In this location, which by design has no anchors, the expansion joints will restrain the offset region by expanding approximately 5/8", well within the limits of travel of the joint.

The 12" offsets at the long straight sections see axial forces of less than 100 lbs because the flow rate at these locations is even less than in medium straights. This force is also restrained by expansion joint extension.

There are also radial forces at these offsets which cancel, but do induce a small moment into the pipe which is easily restrained by the guide brackets.

IV. Component Review

This section will discuss qualitatively the origins and meanings of the pressure ratings shown in Table I. Table I, the heart of this report, lists the item in question, the failure modes analyzed, the pressure at which failure occurs, the recommended safety factor for operating, and the resulting recommended operating pressure. The Appendices then give the detailed quantitative calculations or references which support the data given in Table I.

The items analyzed in Table I fall naturally into two groups:

1. Pipe, elbows, tees, bellows (expansion joints), and flexhose. At what pressure are they expected (by calculation or experiment) to rupture? We follow standard engineering practice and recommend that operating pressure be limited to 1/4 (safety factor 4) the rupture pressure. At what pressure are they expected to exceed the inelastic yield point, leaving items which are slightly deformed? As a safety factor against this mode of "failure," we use our judgment depending on the function of each item.

2. Mechanical strength of anchor points. Whenever there is a 90° turn in the 8" pipe adjacent to an expar-ion joint there is a force on the elbow equal to the pr e times the thrust area of the expansion joint (62 sq. ...). If the anchor on that elbow fails, either a bellows in the system expands to its limit and ruptures, or 8" pipe in the vertical riser past the 90° elbow must take the load or fail. The same failure mode exists at valves in the 8" line (such as at the DTA regions), in which the anchor at the valve (if the valve is closed) must bear the full force. In the evaluation of anchor-point strength, we have adopted a safety factor of 4 on matters involving ultimate strength of bolts, U-clamps, and Unistrut beams. We have adopted a safety factor of 2 or 3 (manufacturer's recommendation) on matters involving frictional slipping, such as Unistrut nuts slipping in the Unistrut channel.

There are around the ring, the following locations where jogs, offsets, elbows, or exits requiring adequate analysis for proper anchoring. These locations are:

a. All DTA regions (18 places).

b. All feedcan regions (24 places).

c. End anchor regions (8 places); B49, C11 (CØ straight), C49, D11 (DØ straight), D49, E11 (EØ straight), E49, F11 (FØ straight).

d. Reaction anchors (6 places); A49, B11 (BØ), B49, C11, B49 + 40' twice (CØ ceiling - run penetration).

e. All medium straight sections (6 places).

f. All 12 location jogs (5 places).

g. All 48 location jogs (5 places).

h. AØ special regions; A12 wall anchor, A12 ceiling anchor, F47-3 penetration region, F47 ceiling anchor, F47 wall anchor.

We now discuss Table I line-by-line.

I. Bellows (expansion joint). Richard Landwere, an engineer at Flexonics (the company which built 80% of the bellows in use), has verbally told us that the operating pressure for this bellows is 120 psig and that the deformation pressure is 180 psig. During a second phone call to him, he told us that the deformation pressure (180 psig) was in fact selected to be 33% of burst pressure, and the operating pressure was selected to be 95% of squirm pressure. His definition of squirm pressure is the pressure at which the bellows will squirm <u>while being stroked</u> and be left with a small inelastic deformation. For his written confirmation of this information, see Appendix C.

A destructive test program of the expansion joint was initiated. In the first test, a bellows was capped off and restrained from stroking from its neutral position; i.e., no compression or extension, ends parallel, and no offset between the two ends. The internal pressure was gradually raised to 230 psig, during which it grew radially by about 0.003". At around 180 psig, the convolutions were noted to be a few mils collapsed. At 230 psig, the bellows suddenly squirmed beyond the inelastic yield point (but did not rupture). In the second test, the bellows was compressed 1" (simulating the tunnel condition of most bellows before a quench), the two ends were offset by 0.5" (simulating the manufacturer's recommended maximum, but exceeding typical tunnel installation errors by a factor of 2 to 4), and the ends were non-parallel by 1° (simulating the worst possible tunnel misalignment). The expansion joint plastically deformed at 200 psi. See test data, Appendix B.

II. Flexhose Assembly.

a. Braided flex. This hose is squirm-protected by steel braid. The manufacturer's recommended maximum operating pressure is 250 psig, which we believe is 25% of rupture pressure.

b. Spool manifold. A three-convolution bellows on the spoolpiece manifold between the two Kautzky valves and the flexhose can be ruptured. The burst pressure is 600 psig.

c. Relief valve body. The torque transmitted to the flange on the output end of the Kautzky valves on the spoolpieces can tear the aluminum flange. The result here is from an empirical test. See Appendix B.

III, IV Pipe and pipe fittings. The table is self-explanatory. On these items, we have a code to follow.

V. Feedcan region anchor strengths. The header geometry in this area is shown in Fig. 2. First we consider the forces resulting from the operating pressure of the system, taken to be the same on either side of the 90° elbows which turn the flow upward, since there are no valves in the system. In this case, there is an equal and opposite force on the two elbows tending to draw them together. An offset aluminum tie bar has been inserted between the two elbows to restrain this motion. The question is, at what pressures do the tie bar and its mating pipe bracket fail? Because the box beam of the tie bar is offset towards the aisle from the force center (i.e., the CL of the pipe), it is subject to torque which tends to bow the beam. The standard moment calculation for this beam (see Appendix A) leads to the result shown in Table I, Item V.a. The tie bar bracket which is welded to the pipe elbow also has a finite strength which is too difficult to calculate. A sample assembly was therefore load tested to failure in a press. The result was that the pipe itself buckled at the weld point at 29,000 lbs force.

Secondly, we consider the effects of small pressure differences which might develop across the feedcan area which result from the impedance of the elbows and the tee when a quench has occurred in only one side of the cryoloop. George Mulholland has calculated the maximum pressure difference expected (see Appendix A) and obtain 4 psig. This would result in a force of 250 lbs total on the two wall anchors which secure the vertical legs to the wall (see Fig. 1). Items Vc, d, e, and f are the recommended pressure differences resulting from the strength of various components of the anchor system, and should be compared with the calculated 4 psig expected maximum, mentioned above.

VI. Double-turnaround regions. See Fig. 3. At the double-turnaround region, there are two butterfly valves in the 8" line, either one of which could be closed. Although the probability is very small that one would be closed during powered operations, it could happen, and might be followed by a 1/4 sector quench (in fact, closing a valve might induce such a quench). Therefore, we propose that the double-turnaround anchor system be capable of withstanding the full force resulting from the maximum allowed operating pressure times the thrust area of the expansion joint.

There are four anchors in the double-turnaround region. Each consists of a metal strap torqued quite tightly around the pipe. The strap is welded to an 8" by 10" plate which is bolted to the wall with four 1/2" bolts. The most likely failure mode (i.e., the one occurring at the lowest pressure) is frictional slipping of the pipe through the strap. The force on the pipe necessary to make it slip in the strap has been measured at E21 as a function of the torque applied to the strap bolt (see graph in the Appendix). At a very reasonable torque of 40 ft/lbs, the pipe slips at a force equivalent to 50 lbs pressure. Multiplying by four anchors but dividing by a safety factor of 2 leads to a pressure limit of 100 psig. If a safety factor of 3 is desired, the maximum pressure is derated to 66 psig. The frictional slipping could be removed.

The ultimate strengths of the strap, bolts, and wall anchors have also been calculated.

VI-X Straight Section Anchors.

In the straight section regions, anchors are installed to restrain the header at the points where the header turns 90°. These anchors must bear the full expansion joint thrust force plus the gas flow inertial force or else the piping and/or expansion joint will fail. End anchors at station #11 and #49 regions are typical throughout the ring exclusive of the AØ straight section anchors. In this region a special arrangement of slings, wall anchors, and penetration anchors are used. A listing of the individual specialized anchor points appears in Table I.

In addition to the end anchors in the BØ and CØ straight section, additional reaction anchors are required. Their design is similar to the end anchor but differ in the way that they are attached to the pipe.

XI-XII Expansion Joint Guide Assembly and Pipe Support Assembly.

These assemblies must primarily be capable of supporting the weight of the pipe and secondly be capable of restraining a radial motion of the header. Each bracket can withstand a working load equivalent of 100 ft of header. The only time at which a bracket might possibly see this loading is during a cooldown when in the past we have observed pipe bow. (See Appendix D.) this level of loading was still equivalent to only 40 ft of header.

The radial loading of the guide and support assemblies is generated primarily by the pressure in the header. Due to the arc in the header, an outward radial force of 775 lbs for a header pressure of 100 psig is generated. This force is assumed to be somewhat equally distributed over the 20 brackets that support the header in that region, or 38 lbs/bracket. The force holding the header in place is the weight of the header itself. A radial movement would have to lift the header out of its rollers. The force to do this for the 45° roller angle is equal to the weight of the pipe. For our case the supports are every 10 ft, making the weight per bracket equivalent to 100 lbs. At the ends of the arc near the expansion joint, guides are installed. The guides can see a greater radial force on the order of 150 lbs. These guides are also installed at regions adjacent to where expansion joint and pipe jogs are present. This offset generates a moment which requires a restraining force of 200 lbs. The guides can restrain 240 lbs.

XIII Relief Valves.

The 50, 12, and 6 psig relief valves used on the 8" header are of "in-house," spring loaded, parallel plate design. The listed relief pressure is the pressure at which the valve <u>begins</u> to open. Any travel of the sealing plate will compress the spring, thus requiring a greater pressure to hold open. The sealing disc transmits the pressure and gas flow inertial force to the springs and then back to the relief flange through a combination of studs.

The 6 spig relief valve on the refrigerator building has six 3/8-in. diameter studs restraining the disc, the 12 psig relief valve at the compressor building has 12 3/8-in. diameter studs and the 50 psig tunnel relief valve has four 1/2-in. diameter studs. Each is capable of withstanding the inertial and pressure forces which will act on them during a quench.

XIV Above Ground Piping.

As stated previously, most of the 8" header is located in the Main Ring tunnel enclosure. The header does exit the tunnel at the 24 refrigerator buildings and adjacent to the six compressor buildings.

The 8" piping at the refrigerator building is comprised of a vertical length of pipe coming up from the tunnel feedcan region with a 19-1/2-in. horizontal offset to clear the refrigerator valve box. This vertical riser then leads through the building roof to the 6 psig main relief valve. Tied into this vertical riser is the 4-in. refrigerator low pressure return gas line. Any contraction of the riser requires that the 4-in. branch line be capable of flexing. Maximum movement will be less than 1/2-in. assuming a temperature change of 200°F.

The above ground piping at the compressor building requires adequate flexibility for thermal cycling without over-stressing the pipe or the anchor points. This has been achieved by the use of "L" and "Z" bends in the piping runs. Only the upstream BØ compressor building run requires the use of expansion joints. Each of the compressor building piping runs are unique and each requires some detailed analysis. The use of the approximate method of calculating thermal expansion stresses from Piping Engineering, Chemtron Corp., is used for this analysis (see Appendix A).

On the BØ upstream piping run, the use of a hinged expansion joint assembly was necessary. This hinged expansion joint assembly is made up of two 8" expansion joints, two 90°, 8" elbows, and a 5 ft long filler piece of 8" pipe. To limit the expansion joints to only angular displacement, the expansion joints are equipped with axial restraints - bars welded to either side of the expansion joint with a pivot pin located at the center of bend. This configuration will withstand the full thrust force of the expansion joint. Each expansion joint is equipped with an aluminum shroud to prevent ice and snow buildup.

V. QUALITY ASSURANCE

The quality of welding on the 8" header was controlled by having all welding done by Fermilab welders or pipefitter welders who passed a competence test administered by the Fermilab Weld Shop. The leak check procedures also required a visual inspection of most welds. All welding rod used on the 8" header was Fermilab-supplied "flag tagged" 308L stainless steel.

To ensure that the installation of the header has been executed correctly and that no inadvertent changes have taken place, a prepower checkout of the header system is done under ODH rules. Under ODH rules all jobs must be cleared through the Main Control Room operations chief. This controls activities in the ODH regions to specific tasks that have had prior approval. A copy of the checkout checklist with instructions is included in Appendix F.

VI. RELIEF VALVE FAILURE MODE ANALYSIS

We discuss here the consequences of the failure of one (or many) of the various types of relief valves in the system to open near the proper pressure, and the probability of that happening. We do not discuss the probability of valves getting stuck open since that does not pose a safety problem, with one exception noted below. Our discussion is rather qualitative on many points and may require further quantitative study.

Kautzky Valve Failure

The consequence of a single Kautzky valve failing to open is known at 3500 amps. In an unplanned experiment on the B12 test string, a Kautzky valve failed to open. The valve happened to hang on the one magnet at B12 with a pressure transducer in the single-phase cryostat. The peak single-phase pressure in that magnet during the quench was 25 psi higher than usual. (See Koepke and Martin, UPC-154.) Let us assume that this pressure increase is proportional to the square of the current, so that at 4440 amps the additional pressure is 40 psi. Adding this to the extrapolated peak pressure in the cryostat at 4440 amps based on A-Sector testing (see Appendix G) leads to a prediction of an absolute pressure in the cryostat of 245 psia in dipoles and 170 psia in the quadrupole/spoolpiece region.

George Biallas has studied the weaknesses of the cryostat by destructive testing. The bore tube collapses at a static pressure of 325 psia (see TM-1166). The bellows connecting the single-phase lines between magnets shows no sign of damage up to 280 psia (see TM-1165).

The latter test was performed with pulsed pressures simulating the time-dependence of quenches. Eric Larson has performed tests of the strength of spoolpieces under static pressure (see TM-1116). Above 220 psia, there are inelastic deformations; at 340 psia, a weld broke.

Our conclusion is that one Kautzky valve can fail during a full-current quench without damaging anything, but with a safety margin that is a mere 1.15. Furthermore, it should be noted that cryostat pressures during quenches are independent of the number of cells which quench simultaneously (unlike the header pressures), so that our concern here pertains to every quench, not just rare "global" quenches. Therefore, we deem it quite important to detect promptly that a Kautzky valve has failed to open so that it can be replaced before a second valve fails in the same half-cell.

For that reason, a system which detects the failure of a valve to open during a quench has been planned, but not yet installed. A Klixon switch which opens at 0°C will be installed on each Kautzky valve. The failure of any one of the six Klixons in each half-cell to open during a quench of that half-cell will be detected by the computer which will set an alarm. Then in-tunnel testing must be done to determine which of the six valves (or Klixon switches) is faulty.

Until this system is installed and tested, some stop-gap operational testing is being done, and periodic retesting is being contemplated. In addition to the thorough bench testing of each valve, the valves are tested in the final installed system as soon as a sector gets "cool" (30°K). The Kautzky valve is a normally-open valve which is closed by the application of control pressure to the back side of a bellows which drives the shaft and poppet. The control pressure and the cryostat pressure at which the valve is opened are linearly related. In this system test, the control pressure is set to zero for two minutes, opening all the valves in a cryoloop and flowing enough helium through to chill, or even frost, the valve bodies. A rapid walk-through is made to determine that each valve body is cold. Thus, each valve is known to be <u>initially</u> good.

However, there are fail-closed modes of failure which can be caused by quenches (see below). We are considering requiring periodic retesting of parts of the system until the Klixon system is installed. The periodicity and selection of which cryoloops to retest are obviously determined by quench history. Lastly, we note that there is very little hope that the Doubler current will exceed 4000 amps for a couple years, which lowers the peak cryostat pressures mentioned above by 30 psi.

We now summarize very briefly what is known about the probability of a Kautzky valve failing to open. The full report on A-Sector and MTF failure statistics is enclosed as Appendix G. The Kautzky valve will fail closed if the poppet becomes detached from the stem, or if the stem breaks, or if the stem separates from the plate on the top of the bellows. In the Mark III version of the valve tested extensively in A-Sector and at MTF, separation of the shaft from the top of the bellows at the structural weld between the two pieces was a major cause of valves failing closed. This problem has been solved in the Mark IV version of the valve by changing the shaft into a "nail," so that the weld between the shaft and the top plate of the bellows is responsible only for keeping the bellows leak-tight, and not for the structural connection between the shaft and the bellows.

Once during the A-Sector quenching a poppet separated from the shaft. The valve failed to open for several quenches before our attention was drawn to it by the observation that the top of the bellow's housing was badly "domed," a result of the extra 40 psi pressure in the unrelieved magnet. A post-mortem on the valve indicated that the snap ring which held the poppet to the foot of the actuator shaft had not been fully seated in the snap-ring groove during the initial assembly of the valve.

This is merely an example of a failure which did happen and which is not detectable at the moment. Furthermore, it is the only fail-closed incident in all of the MTF and A-Sector quenching other than the cracked weld cases mentioned above (a solved problem). All the valves used in A-Sector have been removed and retested. This one failure is the only empirical basis for a failure probability calculation. At MTF, 17 valves have survived a total of about 11,000 quenches. In A-Sector, 160 valves endured a total of 2,000 quenches.

This data leads to two separate probability statements. The probability of improperly installed snap rings is, so far, 1/177 per valve, but must depend strongly on the care of the technician who installed the snap ring. A quality control step which is now being added to the assembly process should reduce this probability to $(1/177)^2$, or 3×10^{-5} per valve, in Sectors A, B, and C.

The second statement is that the probability for damage as a result of quenching which leads to a failure closed on the next quench is less than 1/13,000 per valve opening. There are 1,203 Kautzky valves in the helium system, and 14 valves open on each full-cell quench. If we make the rather "worst case" assumptions that there are two full-cell quenches per day and that the Doubler operated two-thirds of the year, there would be 7,000 valve openings per year.

Thus, we might expect to experience seven detached poppets early in the life of the machine and other failures about every other year. All of these predictions are based on one event, and hence have "error bars" given by Poisson statistics.

Since the Kautzky valve control pressure for an entire quarter-sector is set by a single pair of helium bottles and regulators, it is possible to defeat the relief valves on four adjacent cells of magnets by overpressuring the control gas system. The following redundant safeguards have been implemented to prevent such an occurrence. The regulators on the bottles are 50 psig regulators; setting the regulators to 50 psig changes the cryostat pressure necessary to open the valves to 61 psig, which is still safe. If a regular fails and pressurizes the system to 2,000 psig, there are further safeguards. On the manifold between the bottles and the tunnel there are <u>two</u> 50 psig relief valves (see Fig. 7). These valves are tested <u>in situ</u> after all welding has been done. However, it has never been proven that these relief valves are sized adequately to handle the full bottle pressure without transmitting a high pressure to the tunnel. Therefore, the most important safeguard is the pair of overpressure switches on each manifold. These switches are set to alarm at 5 psig above the normal operating pressure and are tied to the refrigerator permit through the computer. There is some redundancy in having two switches; however, it remains to be proven that they fail-safe if the control chassis fails, which is common to both switches.

<u>Parallel Plate Header Relief Valves</u>

There are three kinds of spring-loaded, parallel plate relief valves on the header itself (see Fig. 1): 8" diameter valves set to crack open at 6 psig at the top of each refrigerator building; two 8" diameter valves set to crack open at 12 psig on top of each compressor building; and two 4" diameter valves set to crack open at 50 psig at each double turnaround region. We pose the same two questions about these valves as we did about the Kautzky valves: what are the consequences of one of them failing; and what is the probability of failure? Our discussion is quite qualitative; we have neither the statistical experience such as we have with the Kautzky valves nor worst-case flow calculations.

However, in this case we are not all concerned with the normal one-cell quenches, as we were with the Kautzky valves. In a one-cell quench, all the header relief valves could fail closed and the gas would expand around the four-mile circumference of the header without overpressuring anything. We are concerned only with "global" quenches and the local equivalent of a global quench, namely, an incident in which the header valves at both ends of a quarter-sector accidentally close and the whole quarter-sector quenches.

The worst "global" quench imaginable is a whole-ring quench and the most probable cause of such a quench is an unforeseen glitch in the quench protection software. In the four months of A-Sector power tests, there were two spontaneous whole-sector quenches, both attributed to software shortcomings. Despite software improvements, the header relief system must be prepared for the worst case. If we make the tentative assumptions that all 72 parallel plate relief valves have the same flow rate, and that the pressure in the header rises linearly with the number of failed valves, then 10% of the valves could fail to open in a whole ring quench without exceeding the 100 psig limit on the header pressure (providing of course that the failed valves are scattered randomly around the ring).

In the case of header isolation valves accidentally closing off a quarter-sector, followed by a quench of the whole quarter sector, there is still three-fold redundance: one 6 psig relief valve above the refrigerator building and two 50 psig reliefs in the tunnel next to the isolation valves. We do not know empirically, nor have we tried to calculate, how much the pressures would rise if one of the three failed. However, there is already indirect protection against this accident in the following form. If any single header isolation valve closes, a compressor rapidly "starves," which should lead to a refrigerator alarm well before the magnets start warming. The refrigerator alarm should lead to a current "dump" without heaters firing. In addition, the microswitches on these header isolation valves could be wired directly to the refrigerator permit. This protection warrants further investigation and possibly testing at low currents.

We know very little about the probability that one of these valves will fail closed. In the design, attention was paid to guiding the springs so that snagging or buckling appears to be impossible. The valves are bench tested before installation. All relief valves in the A-Sector test were observed to have opened during at least one quench. It is recognized that the outdoor valves are exposed to the possibility of freezing shut with iceballs during the winter, so snow protectors have been installed. All relief valves are periodically inspected for iceballs, but this periodicity is not well controlled.

Hazards Involved if Relief Valves Fail Open

If a Kautzky valve fails to close following a quench and will not reseat after torching the valve and "popping" the actuator, then it must be replaced. A procedure has been developed (see Appendix G) and tested 13 times in A-Sector which allows changing the valve with the single-phase and two-phase systems at 20°K and 2.5 psig, and the header at 2 psig. The procedure involves special tools which quickly cap off the single-phase and flexhose during the replacement so that a minimum amount of helium is vented into the tunnel. Three different one-phase plugs are available to the team in case one of the plugs breaks. The team changing the valve must be led by a cryogenics specialist who is experienced in changing valves, and the team must "talk through" the procedure before entering the tunnel. Nonetheless, there is a small chance that they might lose control of the situation, inert the tunnel, and have to egress wearing the required five-minute escape packs. In the A-Sector experience there was not even a "near miss."

Should a 50 psig relief valve in the tunnel fail to reseat after a "global" quench, parts of the tunnel might be inerted. This failure should detected both by the oxygen monitors and by the failure to build pressure in the header. Since personnel are not allowed in the tunnel during powering of the Saver, there is no immediate threat to personnel. However, care must be taken to valve off the part of the header containing the failed valve and evacuating the helium from the tunnel before admitting personnel to fix the valve.

VII. CONCLUSIONS

We conclude that the header system can be operated at 100 psig with safety factors on individual components between two and four. The highest pressure predicted for the header is 90 psig during a full sector quench. Since personnel are not allowed in the tunnel when the Saver is powered, we are concerned with damage to systems, not personnel. The factor of safety for research vessels used in non-manned areas may be reduced from the usual factor of four required by the ASME Pressure Vessel Code (see National Safety Council, Data Sheet "Pressure Vessels and Pressure Systems in the Research and Development Lab," #1-678-79, March 1979, National Safety News).

The worst case accident imagined when personnel are allowed to be present, a rupture of the bore tube vacuum, leads to header pressures calculated to be 50 psig, which keeps all components within the safety factor of four.

Failure mode analysis of the various relief valves in the system indicates that there is sufficient reliability and redundancy in the system that failures of single relief valves to open do not endanger the system. Some loose ends need to be tied up, most notably the role of the pressure switches in protecting against over pressure in the Kautzky valve control system. A decision needs to be made about whether to install a system which detects the failure of any relief valve to open during a quench or whether to impose a periodic retest requirement on these valves.

TABLE I

8" Header Element	Failure Mode	Failure Effect	Failure Pressure (Force)	Safety Factor	Maximum Working Pressure (Force)	Comments
I. Expansion Joint	Inelastic yield of convolutes	Loss of cycle life or leaks	200 psig	2 (with no squirm protection)	100 psig	Manufacturer states 120 psig max. working pressure
II. Flex Hose Assembly (see Fig. 4,5, & 6)						
a. Braided Flex 2" & 3"	Rupture	Leaks	1000 psig	4	250 psig & 375 psig	
b. Spool Manifold	Rupture of alignment flex	Leaks	600 psig	4	150 psig	
c. c. Relief Valve Body	Fracture of flange lip	Leaks	12969 in.-lb torque on flange	3 (with no rotation of valve body) 5.5 with rotation	100 psig 100 psig	Torque transmitted due to alignment flex.
d. Branch to 8" Header	Rupture at weld	Leaks	1500 psig	15	300 psig	No reinforcing required per ANSI 31.3
III. 8" Sch 5 Pipe	Rupture	Leaks	1890 psig	5	378 psig	Per ANSI B31.3
IV. 8" Tees & Elbows	Rupture	Leaks	<1890	>5	158 psig	Per MSS SP43 fabricated welded tee
V. Feedcan Region (see Fig. 2)						
a. Tie Bar	Yield of the bar	Excessive stroking of expansion joint and movement of pipe adjacent to feedcan	324 psig	3	108 psig	Assumes <u>NO</u> additional strength due to sharing of load with lateral support structure
b. Tie Bar Elbow Bracket	Deformation of elbow at bracket	Same as V.a.	468 psig (29042 lbs)	4	117 psig	
c. Lateral Support Structure	Slip of Unistrut nuts in Unistrut channel	Same as V.a.	30 psi differential	3	10 psi differential	Assumes no additional strength due to sharing of load on both sides of feedcan thru tie bar
d. Tabs on 8" Pipe Vertical Riser	Bending of tabs	Loading of adjacent expansion joints laterally until expansion joints rupture & yield of 4" feed to 8" header in Refrigerator Bldg. Possible leaks	(11715 lbs)	3.75	(3125 lbs)	

TABLE I (continued)
Page 2

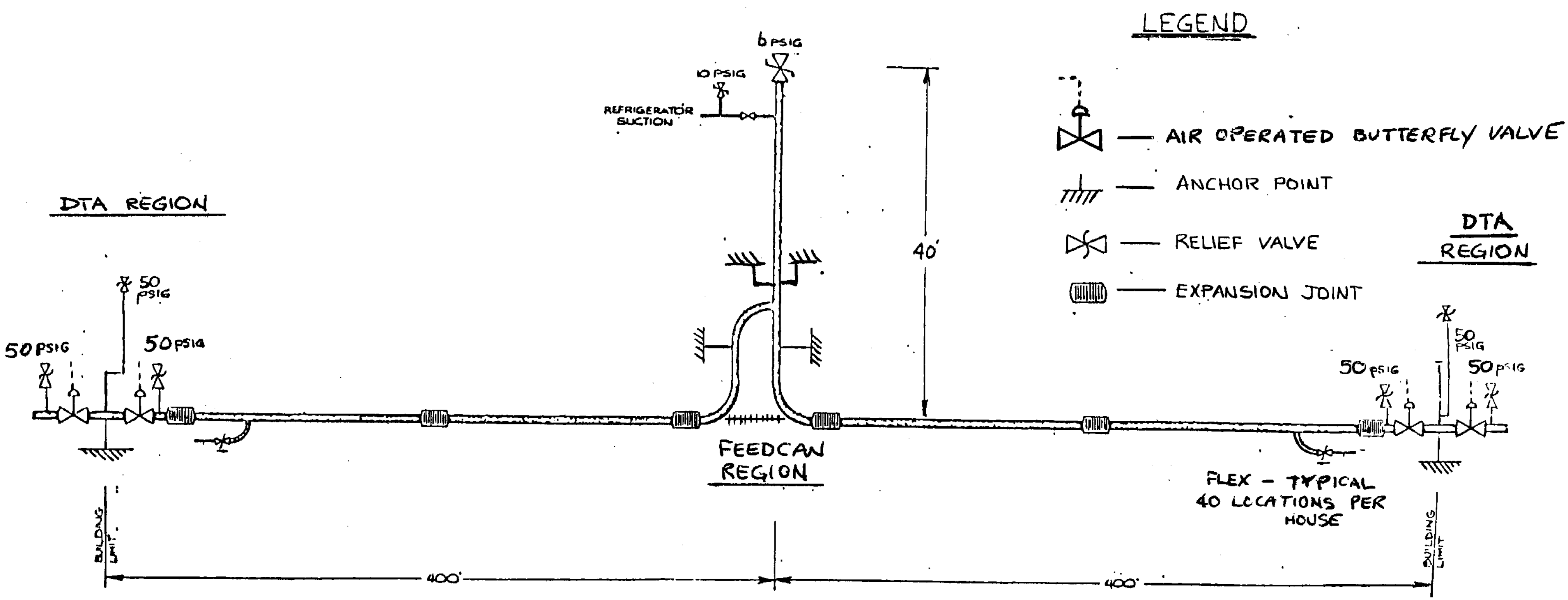
8" Header Element	Failure Mode	Failure Effect	Failure Pressure (Force)	Safety Factor	Maximum Working Pressure (Force)	Comments
VI. Double-Turnaround Region	(see Fig. 3)					
a. Anchor & Support Brackets	Shifting of Header	Bending of cooldown piping. Possible	200 psi differential	2	100 psi differential	Assumes sharing of load between supports and anchors. Straps tightened to yield.
b. 6" Butterfly Valve	Rupture	Leaks	---	---	270 psi	Per manufacturer
c. Fabricated Manifold 6" Pipe	Rupture	Leaks	2234 psig	5	447 psig	Per ANSI B 31.3 Disregards noncircular cross section
VII. A12/F47 Ceiling Anchor	Anchor shear	Excessive stroking of expansion joint possible leaks	416 psig	4	104 psig	Assumes no additional strength due to reinforced U-clamp
VIII. A12/F47 Wall Anchor	Anchor shear	Excessive stroking of expansion joint	495 psig	4	124 psig	Assumes only 2 of 4 bolts takes shear load
IX. F47-3 Penetration Anchor	Pipe deformation	Excessive motion on expansion joint. Possible leaks	468 psig	4	117 psig	Similar to V.b where failure was deformation of elbow
X. 11 & 49 End Anchor Reaction Anchor	Concrete anchor shear	Excessive motion on expansion joint. Possible leaks	580 psig	4	145 psig	Assumes only 2 of 4 bolts takes shear load
XI. Expansion Joint Guide Assembly	Bending of Guide	Excessive motion on expansion joint. Possible leaks	1408 psig	4	352 psig	
XII. Pipe Support Assembly	Concrete anchor pullout	Excessive header movement & damage to flexhoses & any equipment underneath header	(4320 lbs.) vertical (3840 lbs) horizontal	4 4	(1080 lbs) vertical (960 lbs) horizontal	Supports are nominally every 10' or 100 lbs of header. 200' of header would have to lift to attain this loading vertically. Horizontal loading is nominally the rolling friction of rollers, less than 100 lbs. Pipe will not lift out of supports due to pressure in pipe.
XIII. Relief Valves						
a. 6 psi	Bolt failure	High inertial loading at feedcan area. Possible projectiles		4.5	(7244 lbs) combined inertial & pressure forces	Includes inertial forces acting on sealing plate

TABLE I (continued)

8" Header Element	Failure Mode	Failure Effect	Failure Pressure (Force)	Safety Factor	Maximum Working Pressure (Force)	Comments
XIII. Relief Valves (cont'd)						
b. 12 psi	Bolt failure	Loss of gas - Possible projectiles		>4.5×2	$\frac{(\leq 7244 \text{ lbs})}{2}$	Location where used does not see maximum inertial forces
c. 50 psi	Bolt failure	Excessive gas dumping to tunnel		>10	650 psig	Inertial forces not included
XIV. Above Ground Piping	Overstressing of pipe by thermal expansion & contraction	Possible rupture after some cycling		>3	Not applicable	Checked per ANSI B 31.3

FIG. 1

8" HEADER
TYPICAL HOUSE



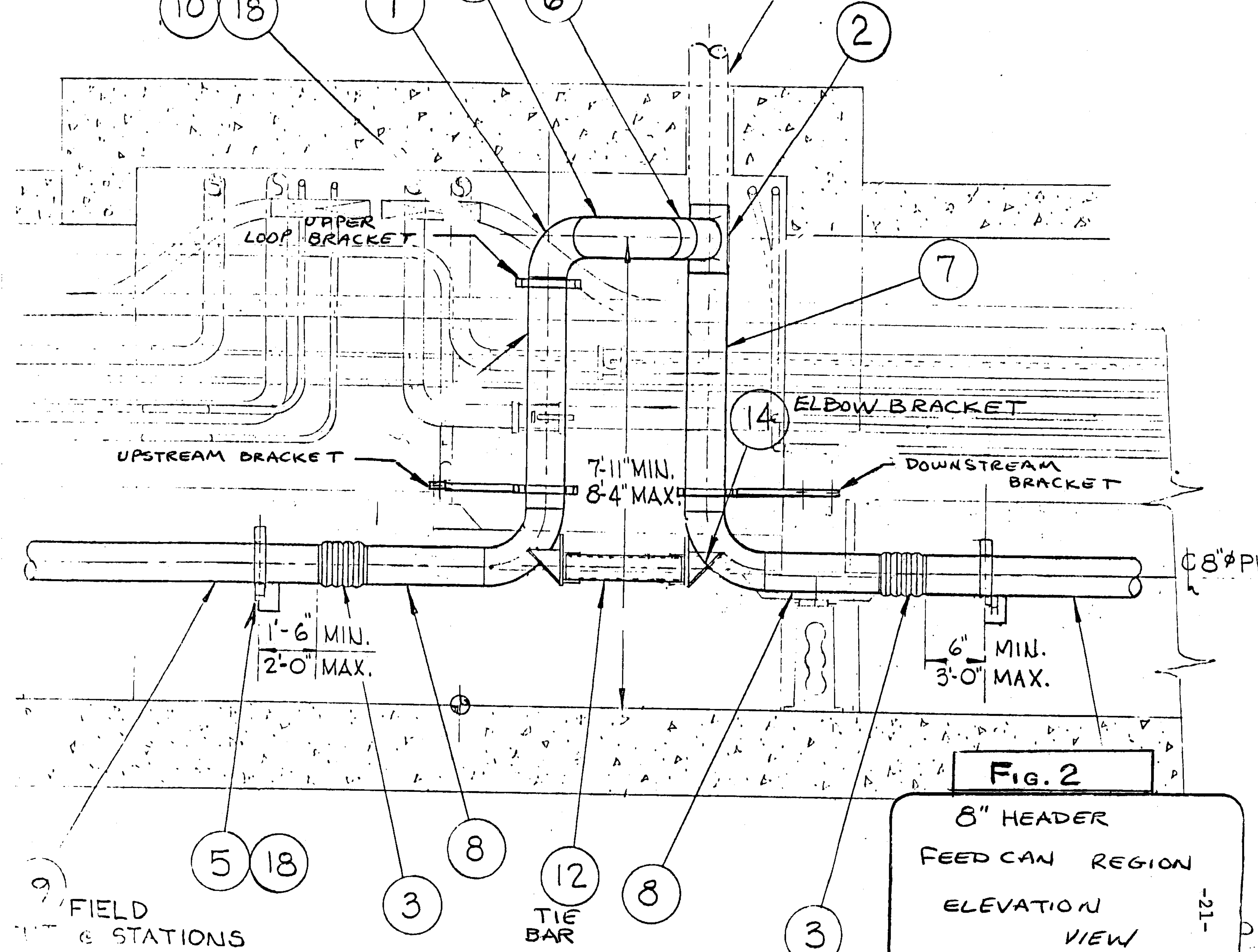


FIG. 2

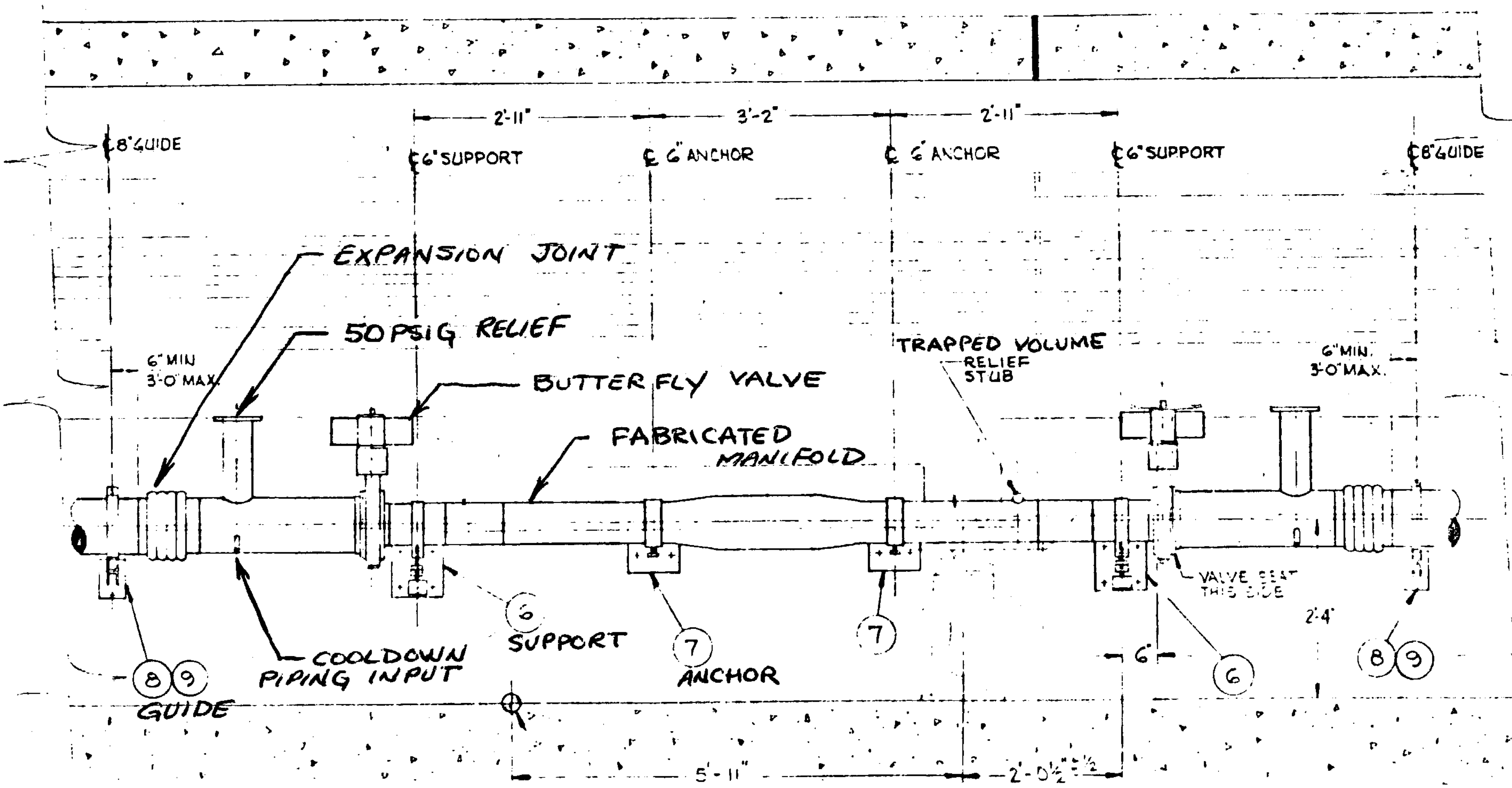
8" HEADER FEED CAN REGION ELEVATION VIEW

FIG 3

DTA REGION

PLAN VIEW

TYPICAL AT 3 PLACES PER SECTOR
18 TOTAL LOCATIONS



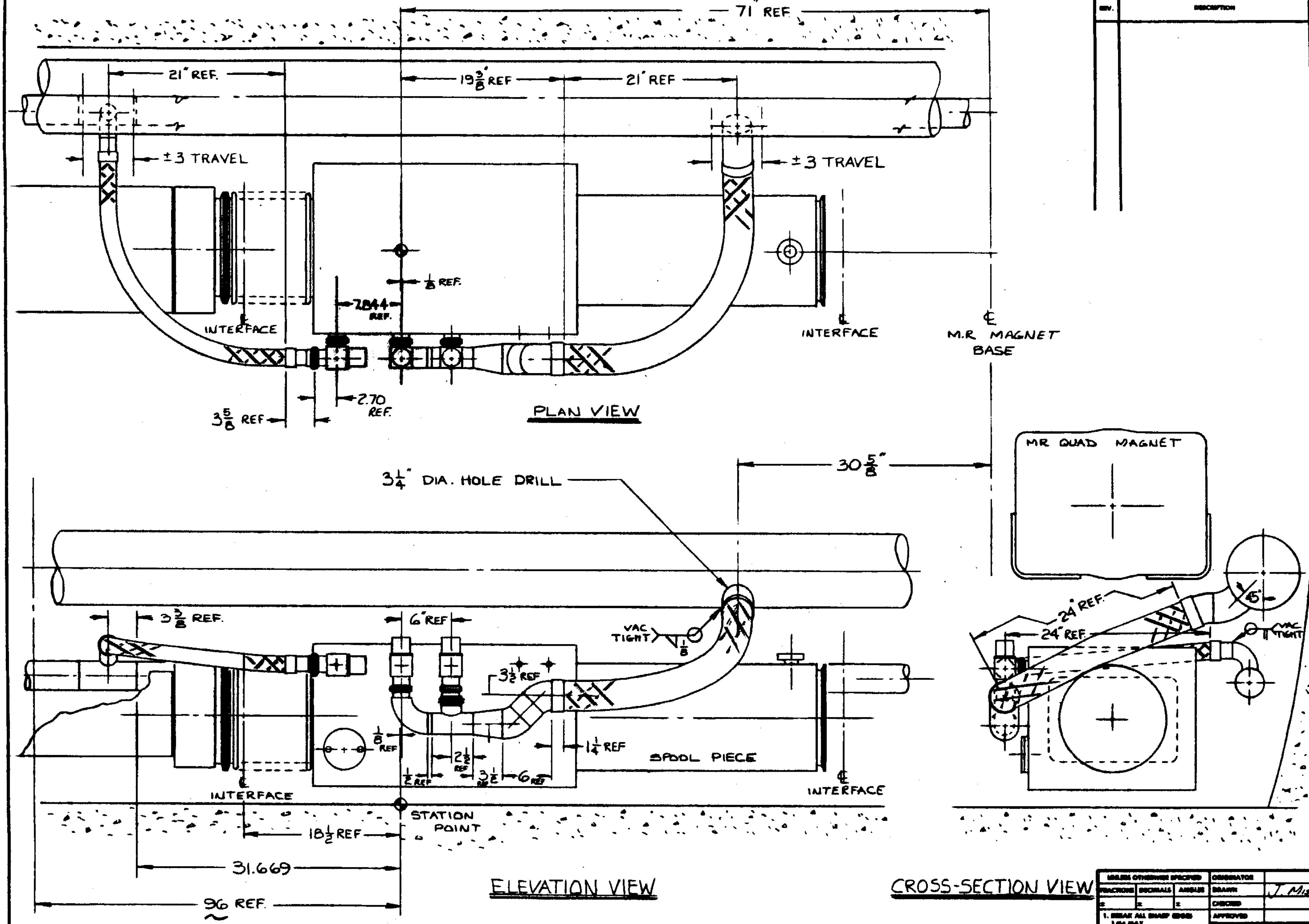


FIG. 4

ORIGINATOR		
DRAWN	J. Mizek	4/2/81
CHECKED		
APPROVED		
USED ON		
MATERIAL-		

FERMI NATIONAL ACCELERATOR LABORATORY
U.S. DEPARTMENT OF ENERGY

ENERGY SAVER
QUAD SPOOL TO 3" & 8" HEADER
TYPICAL FLEX CONNECTIC

SCALE 1/8"=1" DRAWING NUMBER 0428.00-MC-107958

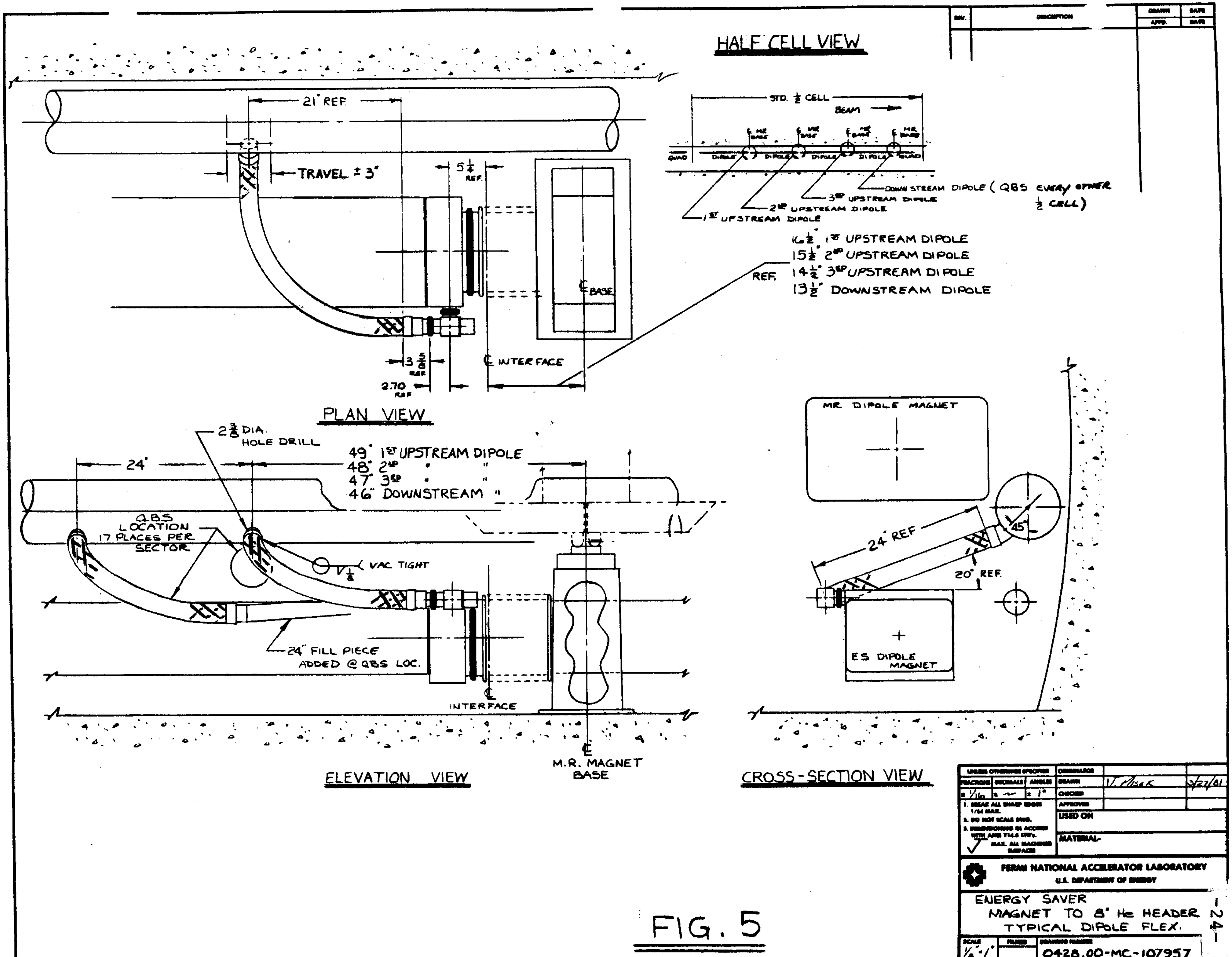
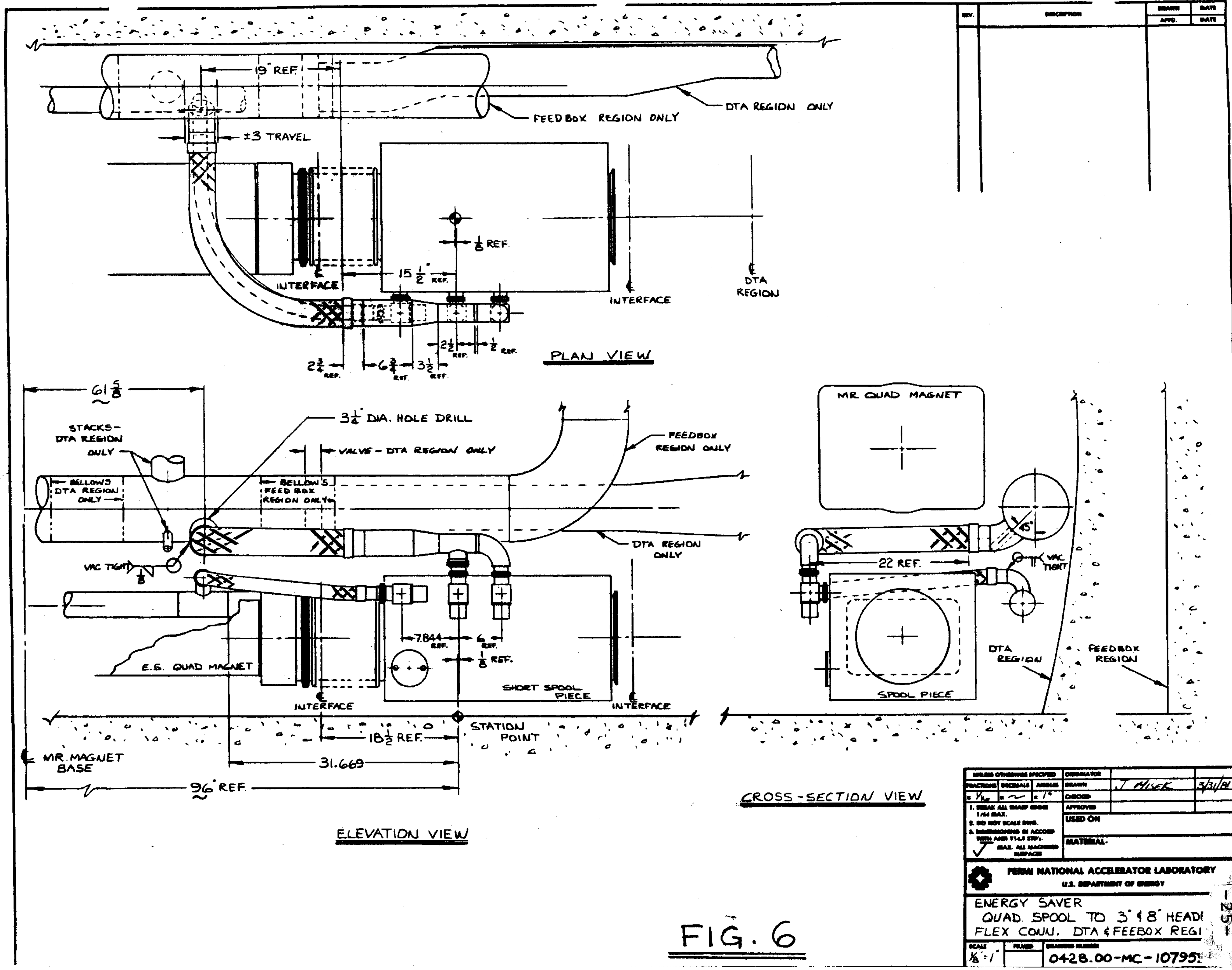
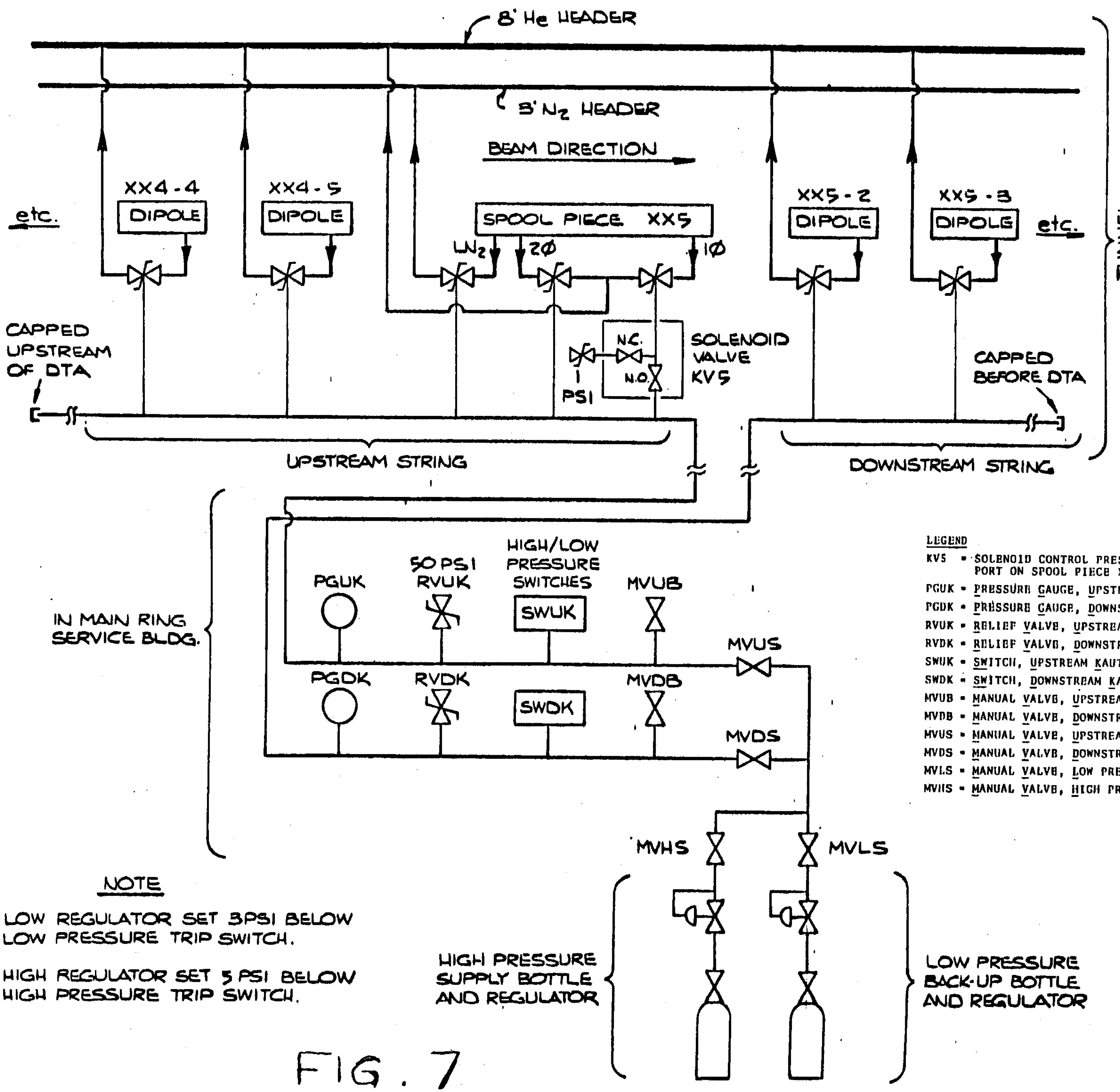

HALF CELL VIEW
STD. ½ CELL
BEAM
℄ MR BASE
QUAD
DIPOLE
1ST UPSTREAM DIPOLE
2ND UPSTREAM DIPOLE
3RD UPSTREAM DIPOLE
DOWN STREAM DIPOLE (QBS EVERY OTHER ½ CELL)
16½" 1ST UPSTREAM DIPOLE
15½" 2ND UPSTREAM DIPOLE
14½" 3RD UPSTREAM DIPOLE
13½" DOWNSTREAM DIPOLE
REF.
21" REF.
TRAVEL ± 3"
5¼ REF.
3⅝ REF
2.70 REF
℄ BASE
℄ INTERFACE
PLAN VIEW
2⅜ DIA. HOLE DRILL
24"
49" 1ST UPSTREAM DIPOLE
48" 2ND " "
47" 3RD " "
46" DOWNSTREAM "
QBS LOCATION 17 PLACES PER SECTOR
VAC TIGHT
24" FILL PIECE ADDED @ QBS LOC.
℄ INTERFACE
℄ M.R. MAGNET BASE
ELEVATION VIEW
MR DIPOLE MAGNET
24" REF
45°
20° REF.
ES DIPOLE MAGNET
CROSS-SECTION VIEW
FERMI NATIONAL ACCELERATOR LABORATORY
U.S. DEPARTMENT OF ENERGY
ENERGY SAVER
MAGNET TO 8" He HEADER
TYPICAL DIPOLE FLEX.
SCALE ⅛"-1"
0428.00-MC-107957
USED ON
MATERIAL-
V. Misek 3/27/81

FIG. 5



19" REF.
±3 TRAVEL
FEEDBOX REGION ONLY
DTA REGION ONLY
1/8 REF.
15 1/2" REF.
INTERFACE
INTERFACE
DTA REGION
2 3/4 REF.
6 3/4 REF.
3 1/2 REF.
2 1/2 REF.
1/2 REF.
PLAN VIEW
61 5/8
3 1/4" DIA. HOLE DRILL
STACKS-DTA REGION ONLY
VALVE - DTA REGION ONLY
FEEDBOX REGION ONLY
BELLOWS DTA REGION ONLY
BELLOWS FEED BOX REGION ONLY
DTA REGION ONLY
VAC TIGHT
1/8
E.S. QUAD MAGNET
7.844 REF.
6 REF.
1/8 REF.
SHORT SPOOL PIECE
INTERFACE
INTERFACE
STATION POINT
MR. MAGNET BASE
18 1/2 REF.
31.669
96" REF.
ELEVATION VIEW
MR QUAD MAGNET
45°
22 REF.
VAC TIGHT
DTA REGION
FEEDBOX REGION
SPOOL PIECE
CROSS-SECTION VIEW
REV.
DESCRIPTION
DRAWN
DATE
APPD.
DATE
UNLESS OTHERWISE SPECIFIED
FRACTIONS
DECIMALS
ANGLES
± 1/16
± 1°
1. BREAK ALL SHARP EDGES 1/64 MAX.
2. DO NOT SCALE DWG.
3. DIMENSIONING IN ACCORD WITH ANSI Y14.5 STD.
MAX. ALL MACHINED SURFACES
ORIGINATOR
DRAWN
J. MISEK
3/31/81
CHECKED
APPROVED
USED ON
MATERIAL-
FERMI NATIONAL ACCELERATOR LABORATORY
U.S. DEPARTMENT OF ENERGY
ENERGY SAVER
QUAD. SPOOL TO 3" & 8" HEADI
FLEX CONN. DTA & FEEBOX REGI
SCALE
1/8"=1"
FILMED
DRAWING NUMBER
0428.00-MC-10795

FIG. 6



FOR MECHANICALS IN MAIN RING SERVICE BLDG SEE DWG 1650-ME-167089

LEGEND

KV5 = SOLENOID CONTROL PRESSURE VALVE FOR KAUTZKY VALVE ON THE 1Ø RELIEF PORT ON SPOOL PIECE XX5, WHERE XX = A1, A2, A3, ...
PGUK = PRESSURE GAUGE, UPSTREAM KAUTZKY VALVES' CONTROL PRESSURE
PGDK = PRESSURE GAUGE, DOWNSTREAM KAUTZKY VALVES' CONTROL PRESSURE
RVUK = RELIEF VALVE, UPSTREAM KAUTZKY VALVES' CONTROL PRESSURE
RVDK = RELIEF VALVE, DOWNSTREAM KAUTZKY VALVES' CONTROL PRESSURE
SWUK = SWITCH, UPSTREAM KAUTZKY VALVES, UNDER/OVER PRESSURE
SWDK = SWITCH, DOWNSTREAM KAUTZKY VALVES, UNDER/OVER PRESSURE
MVUB = MANUAL VALVE, UPSTREAM BLEED-DOWN, KAUTZKY CONTROL PRESSURE
MVDB = MANUAL VALVE, DOWNSTREAM BLEED-DOWN, KAUTZKY CONTROL PRESSURE
MVUS = MANUAL VALVE, UPSTREAM SHUTOFF
MVDS = MANUAL VALVE, DOWNSTREAM SHUTOFF
MVLS = MANUAL VALVE, LOW PRESSURE BOTTLE SHUTOFF
MVHS = MANUAL VALVE, HIGH PRESSURE BOTTLE SHUTOFF

NOTE

LOW REGULATOR SET 3PSI BELOW LOW PRESSURE TRIP SWITCH.

HIGH REGULATOR SET 5 PSI BELOW HIGH PRESSURE TRIP SWITCH.

FIG. 7

UNLESS OTHERWISE SPECIFIED			ORIGINATOR		
FRACTIONS	DECIMALS	ANGLES	DRAWN	D. RICHARDSON	4-6-82
			CHECKED		
1. BREAK ALL SHARP EDGES 1/64 MAX. 2. DO NOT SCALE DWG. 3. DIMENSIONING IN ACCORD WITH ANSI Y14.5 STD'S. MAX. ALL MACHINED SURFACES			APPROVED		
			USED ON		
			MATERIAL:		

FERMI NATIONAL ACCELERATOR LABORATORY
U.S. DEPARTMENT OF ENERGY

SAVER CRYOGENIC SYSTEMS GROUP
RELIEF VALVE CONTROL
PRESSURE SYSTEM SCHEMATIC

APPENDIX A

1. Inertial-Momentum.
2. Beam Tube Break.
3. Spool Manifold.
4. Branch Reinforcement.
5. Tie Bar.
6. Feedcan Region Brackets.
7. Feedcan Region Vertical Riser Tabs.
8. Feedcan Region Forces.
9. DTA Support Bracket.
10. DTA Anchor Bracket.
11. A-Ø Anchors.
12. Penetration at F47 Anchors.
13. Guide Bracket.
14. Support Bracket.
15. Pipe Lift and Moments at Jogs.
16. Above Ground Analysis.
17. Relief Valve Bolts and Flanges and Blankoffs.
18. End Anchor.
19. Reaction Anchor.
20. Feedcan Region Pressure Drop

The contents of this Appendix are filed in the Accelerator Division Safety Files, File no. 1-2.10300.

APPENDIX B

- Test Data -

1. Bellows Pressure Test, 3/8/82.
2. Bellows Pressure Test, 3/11/82.
3. Kautzky Flange and Clamp Failure.
4. Hydrostatic Pressure Test of Kautzky Valve Flange and Two Piece Brass Clamp.
5. Rotational Resistance of Aeroquip Clamp vs. Two Piece Brass Clamp.
6. Pressure Effects on Spool Manifolds.
7. FBA Tie Bar Elbow Bracket.
8. DTA Anchor Slip.

Fermilab

March 8, 1982

To: The File

From: G.T.Mulholland

Subject: HYDRAULIC/PNEUMATIC TEST OF AN 8" TUNNEL HEADER BELLOWS

A Flexonics bellows fabricated to 0428.00MB107559A with the following specifications:

1.	Single ply bellows	0.015" wall min.
2.	Max. spring rate	500#/in.
3.	Stroke	±1/2 in.
4.	Cycle life	7000 cycles
5.	Working pressure	60 psig
6.	Working temperature	200°F to 95°F

constrained to be relaxed, uniaxial and of fixed length was pressure tested. The bellows was filled with water and pneumatically pressurized using the Bubble Chamber relief valve testing cart. The diameter was measured with a bow micrometer and the convolution gap monitored with a feeler gauge.

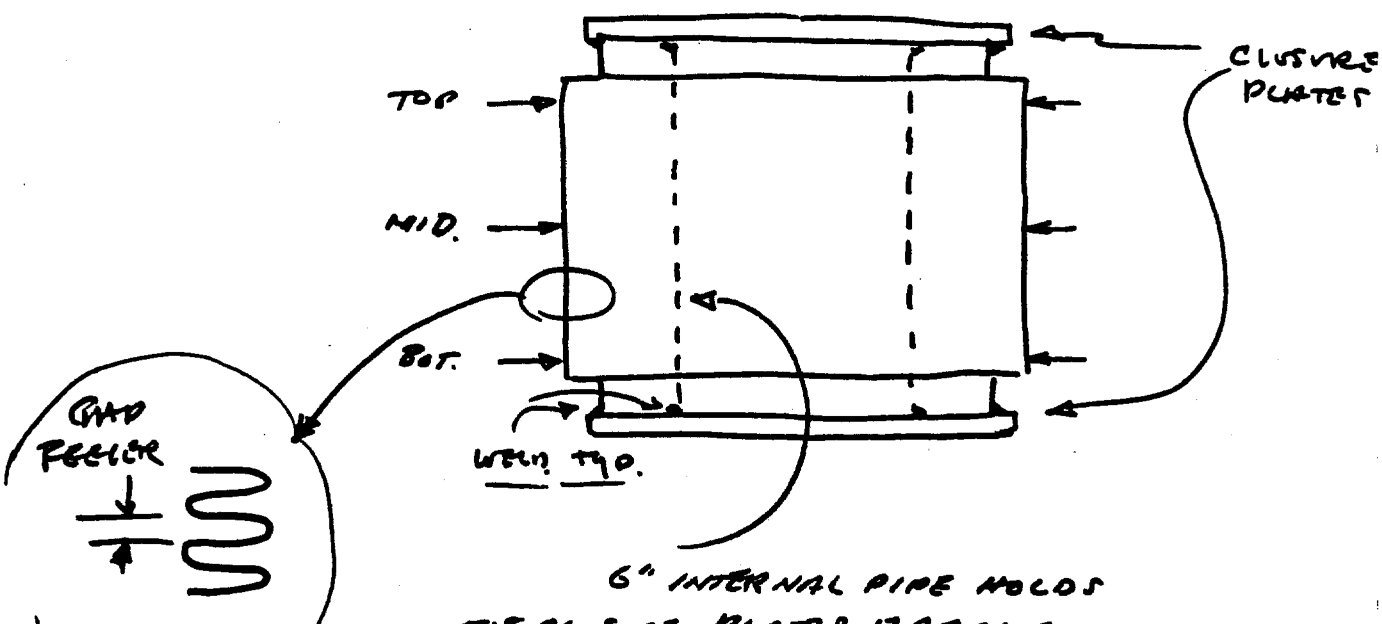
Pictures of the failed bellows will be available from Photography in a few days.

GTM:er
attach.
cc: H.Edwards
W.B.Fowler
J.Misek
C.T.Murphy

8" Bellow Test Data

(3-4-82)

	TOP ⌀	MID. ⌀	BOT. ⌀	GAP FEELER (SET TO NOMINAL CONVOLUTION GAP)
0	9.570	9.564	9.576	
20	9.570	9.564	9.577	
30	9.568	9.565	9.577	
40	9.570	9.565	9.577	
50	9.571	9.565	9.577	
60	9.570	9.566	9.577	
70	9.571	9.566	9.577	
80	9.571	9.566	9.576	
90	9.571	9.566	9.577	
100	9.571	9.566	9.578	
110	9.572	9.567	9.578	
120	9.572	9.567	9.578	
130	9.572	9.566	9.577	
140	9.572	9.567	9.577	
150	9.573	9.566	9.578+	
160	9.573+	9.567+	9.578+	TIGHT
170	9.573+	9.567+	9.578+	
180	9.573	9.567+	9.579	-.004"
190	9.573	9.567+	9.578+	
200	9.574	9.566	9.579	
210	9.574	9.568	9.579+	TIGHT
220	9.574	9.568	9.579	
230	SQUIRM FAILURE - TEST ENDS			



6" INTERNAL PIPE HOLDS THE CLOSURE PLATES PARALLEL AND UNIAXIAL.

8" BELLOWS TEST DATA

3/11/82

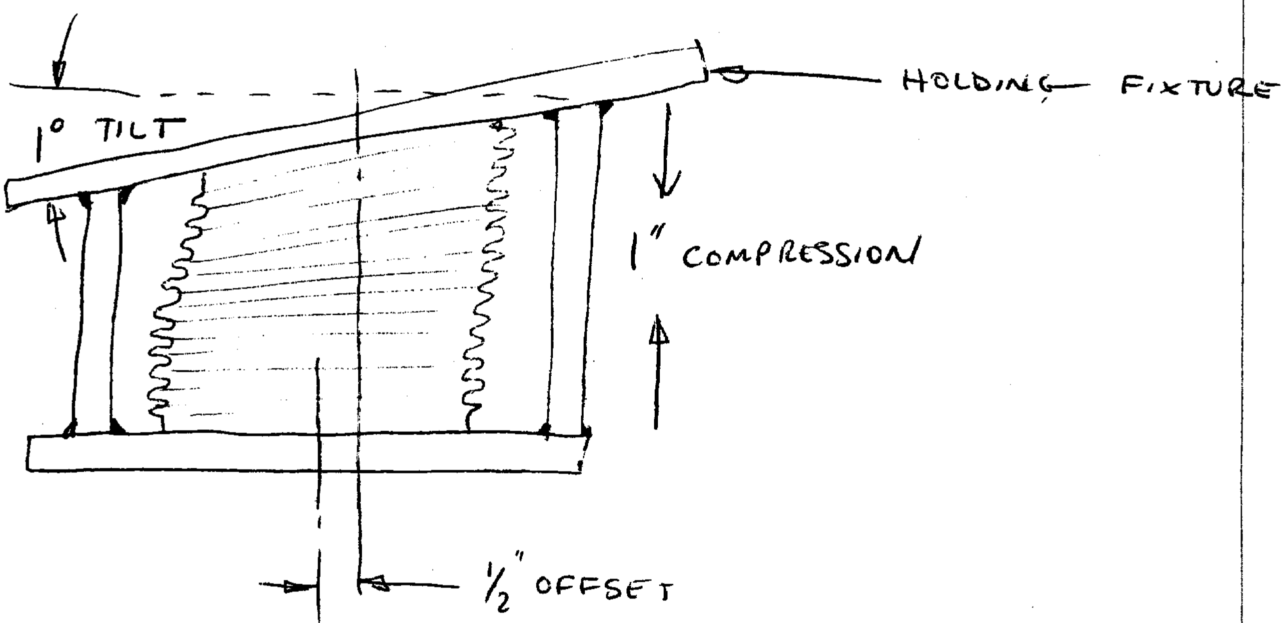
TABULARIZED BY J. MISEK FROM POLARIOD PHOTOS OF TEST SPECIMEN. 5/19/82

BELLOWS SET UP WITH THE FOLLOWING CONDITIONS:

1" COMPRESSION FROM NEUTRAL

1/2" OFFSET OF ENDS

1° TILT (.150" ACROSS 8.625 DIA)



@ 150 psi NO NOTICABLE PLASTIC DEFORMATION OR MOVEMENT

@ 160 psi " " " "

@ 170 psi " " " "

@ 180 psi PECEPTABLE MOVEMENT OF CONVOLUTES DOES NOT APPEAR TO BE PLASTIC

@ 190 psi " " " "

@ 200 psi CONVOLUTES DEFORMED PLASTICALLY

@ 210 psi ADDITIONAL DEFORMATION

@ 220 - 230 SEVERE DEFORMATION. IMPACTED SUPPORT STRUCTURE DID NOT RUPTURE

END OF TEST.

Test: Kautzky flange and clamp failure.

Objective: Subject two piece clamp and Kautzky flange to force perpendicular to axis of flange to observe yield and shear.

Results: Yield appeared at 9392 in./lbs. Could not visually tell what yielded first. Continued increase in force caused plastic deformation of brass. At 12969 in./lbs aluminum flange abruptly sheared.

$9392 \div 6 = 1565$ lbs force at alignment bellows.

Area of alignment bellows

$$3'' \text{ dia.} = \pi d^2/4$$
$$\cong 7 \text{ in.}^2$$

Equivalent pressure in manifold to generate

$$\text{yield torque} = \frac{1565}{7} = 223 \text{ psig.}$$

$$\text{fracture torque} = \frac{12969}{6}/7 = 308 \text{ psig.}$$

Test: Hydrostatic test of Kautzky valve flange and two piece brass clamp.

Objective: Observe localized leak where clamp is split at 450 psig.

Results:

1. No leak observed at water pressure.
2. No leak observed at gas pressure after water was removed.
3. No measured plastic deformation observed on clamp.

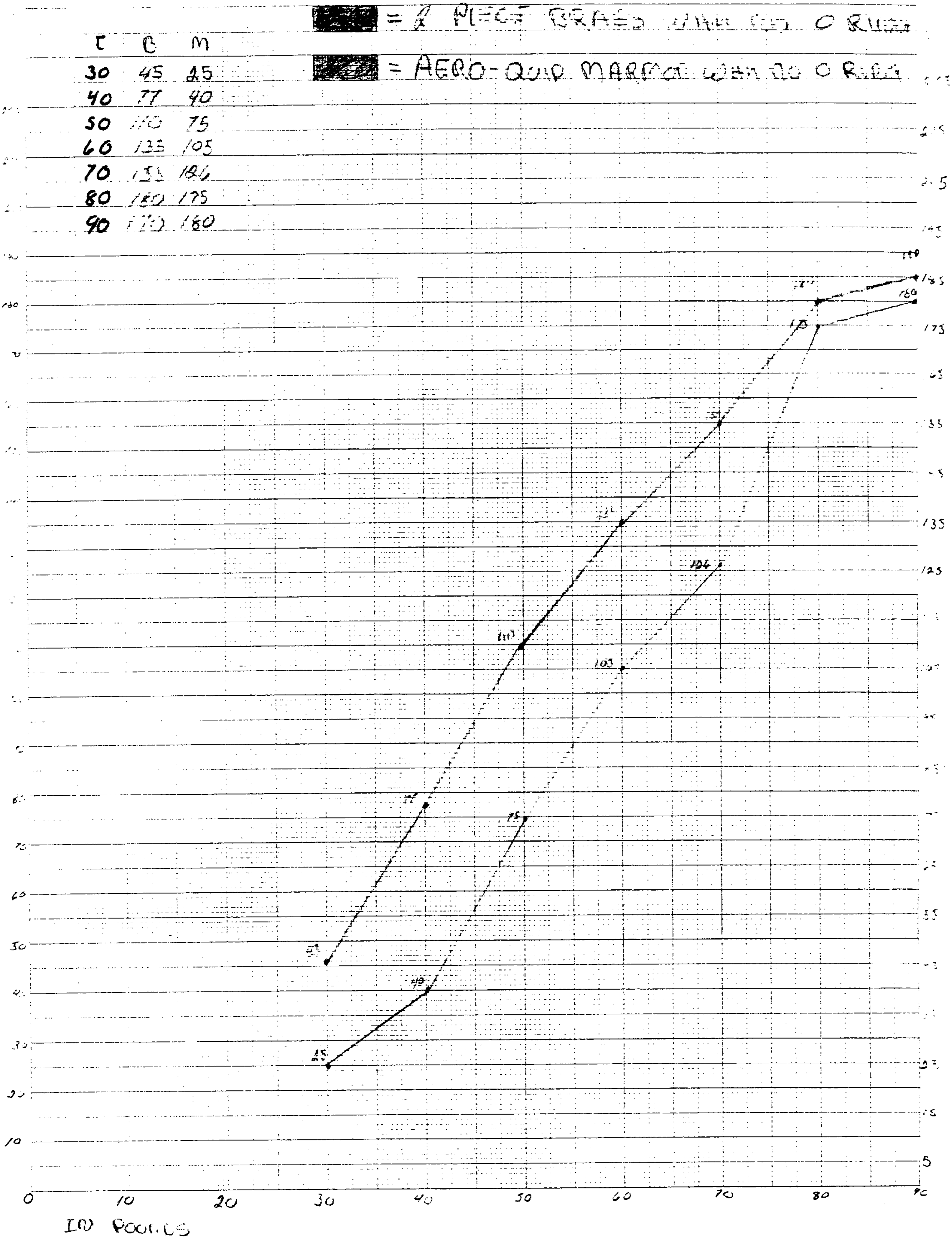
Test: Rotation/resistance test of Aeroquip clamp vs two piece brass clamp.

Objective: Compare both clamps with no O-ring, with dry O-ring and with greased O-ring.

Results: Brass more resistive generally. There was little difference until O-ring was greased. At this time the brass retained its resistance while the Marmon did not. The directional forces between the brass clamp and aluminum flange are a factor while the same between the Marmon and aluminum flange are not.

ROTATIONAL RESISTENCE

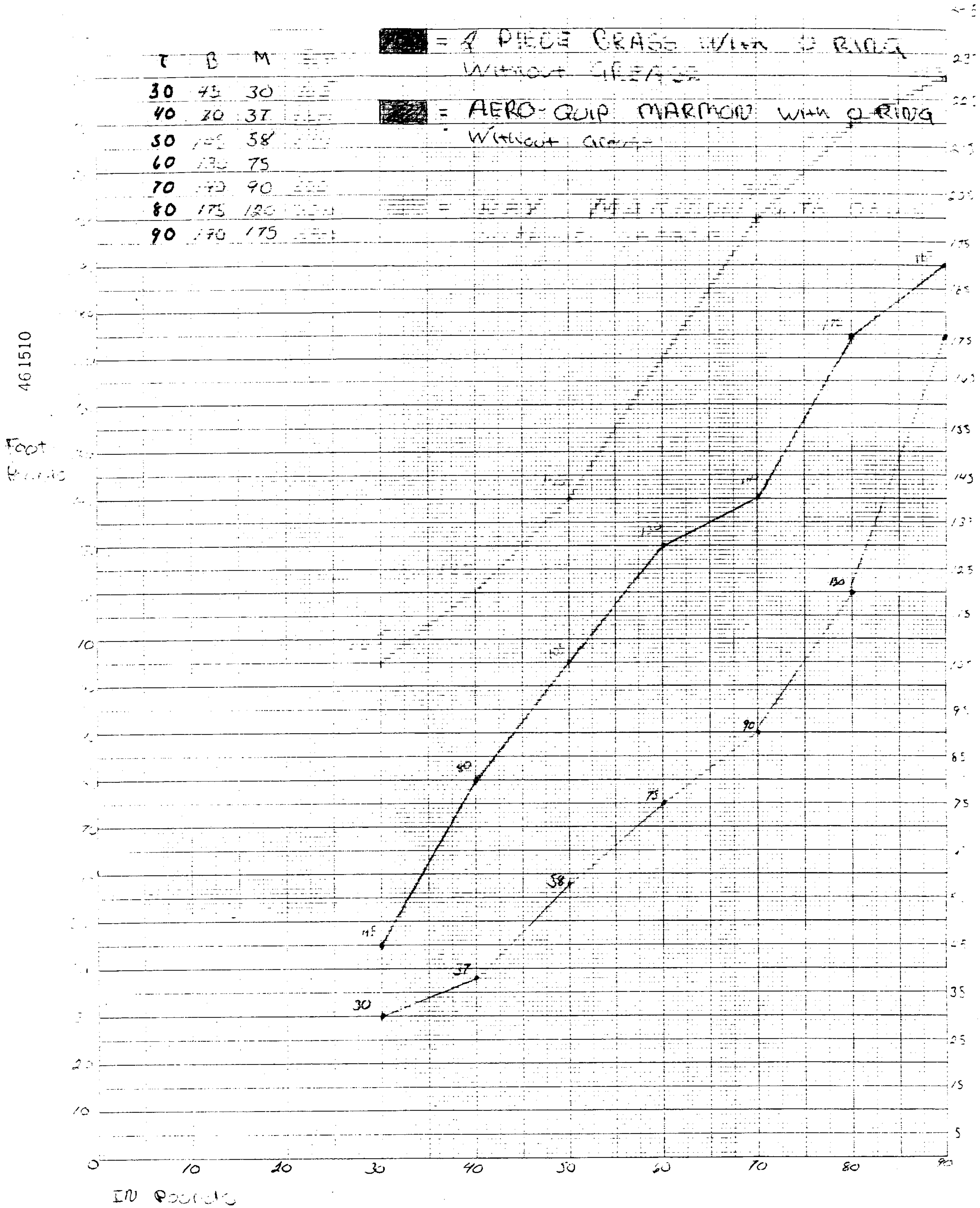
T	B	M
30	45	25
40	77	40
50	110	75
60	135	105
70	155	126
80	180	175
90	[illegible]	180



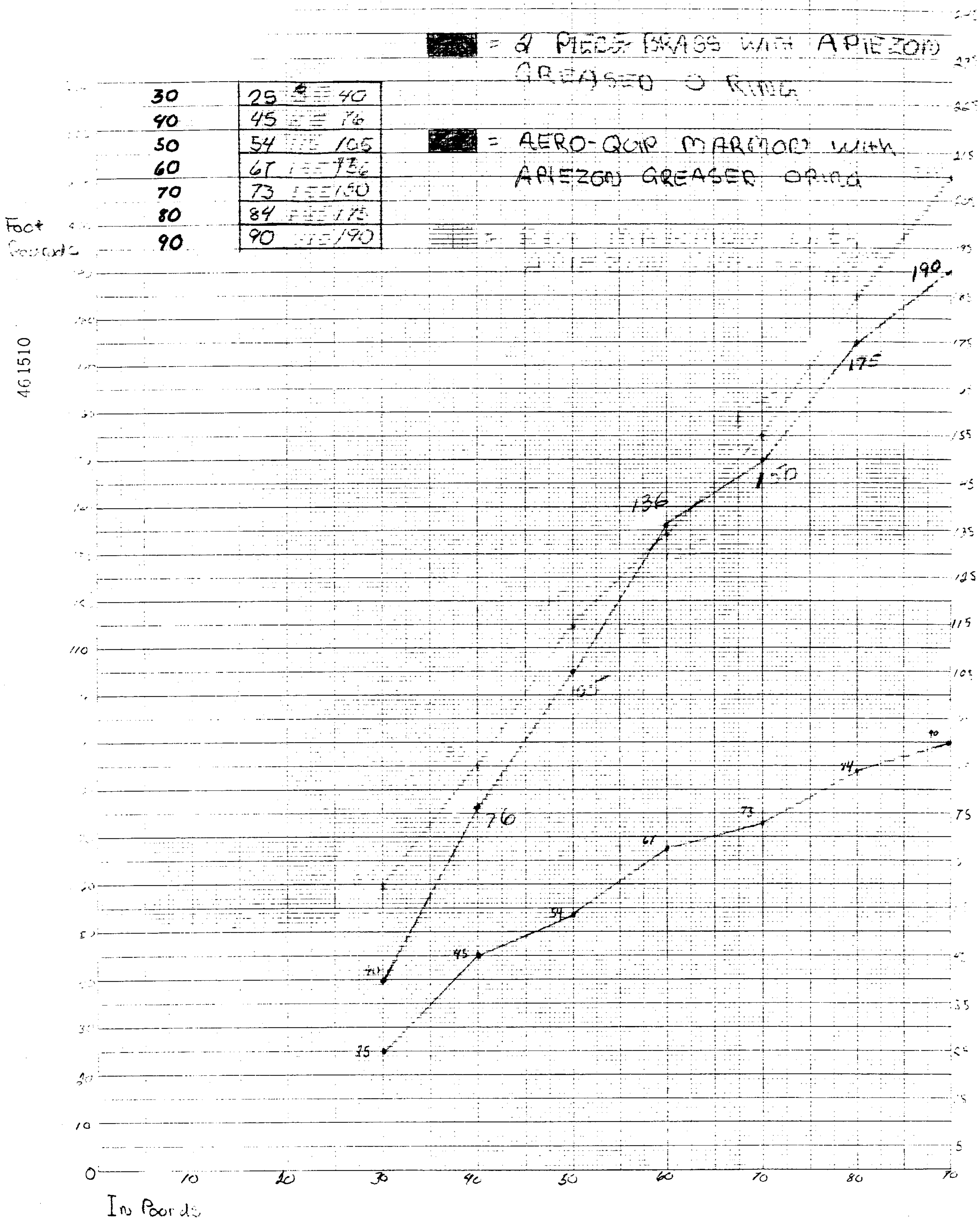
461510

ROTATIONAL RESISTENCE

T	B	M
30	45	30
40	80	37
50	105	58
60	130	75
70	140	90
80	175	130
90	190	175



ROTATIONAL RESISTENCE



30	25	40
40	45	76
50	54	105
60	67	136
70	73	150
80	84	175
90	90	190

Test: Pressure effects on spool manifolds.

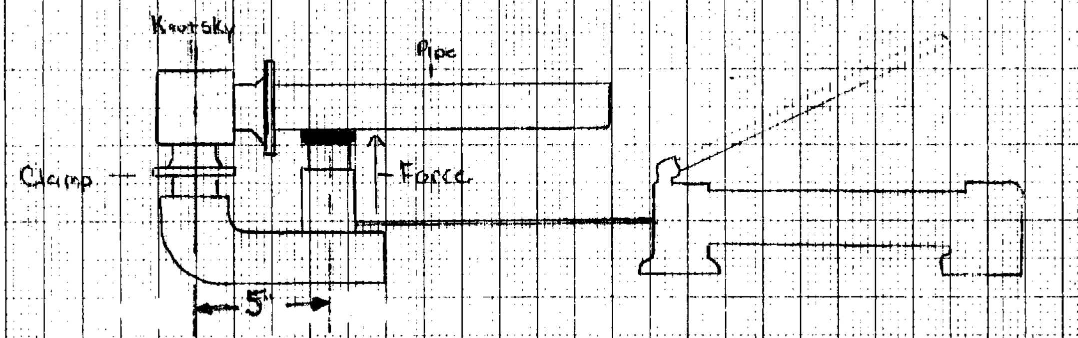
Objective: Subject two different clamps for Kautzky valves to a variety of forces equal to pressures possible in spool, to determine effects on torque settings of clamps.

Results: Per chart.

461510

15te..

Pressure PSIG	Start	Aero-Quip	2 piece Brass
24	90 in lbs	90 in lbs	90 in lbs
49	90 in lbs	90 in lbs	85 in lbs
73	90 in lbs	85 in lbs	85 in lbs
97	90 in lbs	80 in lbs	85 in lbs
122	90 in lbs	75 in lbs	75 in lbs



Start at 90 in lbs of torque on clamp

Force applied 5 times than torque on (it taken again).

Test: FBA tie-bar elbow and bracket.

Objective: Increase force of elbow to failure.

Results:

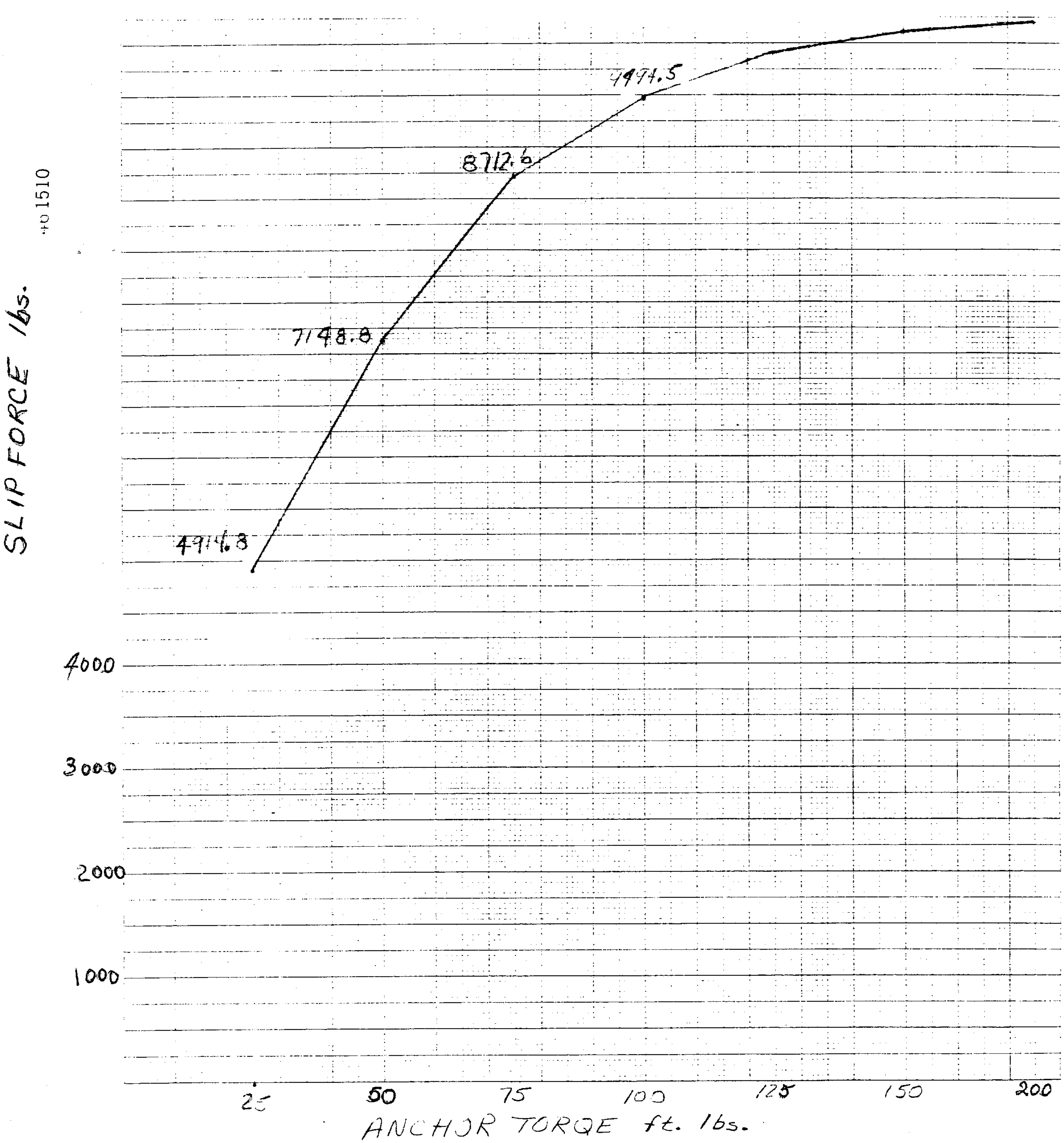
Force-lbs	Comments
15638	Tie-bar plate deflection 1/16". Nothing noted on welds or elbow.
17872	Tie-bar plate deflection 1/8". Nothing noted on welds or elbow.
22340	Tie-bar plate deflection 3/16". Nothing noted on welds or elbow.
24574	Tie-bar plate deflection 5/16". Nothing noted on welds or elbow.
26808	Tie-bar plate deflection 3/8". Relaxed force to observe plastic deformation of plate. Deformation = 1/8".
29042	Elbow abruptly forced on side away from feedbox. Continued force of 22340 lbs caused a uniform rate of further deformation. Stopped test at this point.

Test: DTA anchor slip test (one anchor).

Objective: Determine force required to cause axial movement.

There are normally two anchors at each DTA but only one was used in this test. The results on the graph are the test results times two. There are two additional supports which should offer some anchoring but are not presently considered as such. The penciled portion of the curve is measured and the red is an extrapolation assuming the same rate of diminishing return.

CYLINDER SIZE 2.237 INCHES



APPENDIX C

- Manufacturers' Data and Reference Material -

1. Flexonics letter 3/17/82.
2. Anaconda data sheets for expansion joint.
3. ANSI B31.3, Appendix A.
4. MSS, SP43.
5. Flexweld data with Fermi specs for Flexonics fabricated hose.
6. Fermilab spec for Flexonics and Flexweld fabricated alignment flex.
7. Unistrut data.
8. Hilti data.
9. Hills-McCanna data.

Flexonics Division
300 East Devon Avenue • Bartlett, Illinois 60103
Telephone 312-837-1811 • Telex 72-2455

March 17, 1982

NAL Fermi Lab
PO Box 500
Batavia, Illinois 60510

Attn: Joel Misek

Dear Mr. Misek:

Confirming your phone conversation of 3-10-82 with Dick Landwehr of our Bellows Degisn Engineering Deparmtent, following is the data covered. On NAL P/N 0428.00-MB-107559, our P/N 100-838-5001, the bellows assembly has a calculated burst of 878 PSIG, deformation of 180 PSIG and squirm of 120 PSIG. The squirm calculation includes a factor as applicable to dynamic squirm as might occur during axial stroke with no offset of the ends.

Based on the above, we would recommend the maximum working pressure to be 120 PSIG. At this pressure, the calculated stress would be 34,000 PSI. At the 120 PSIG working pressure, the safety factor is just below the recommended 4:1 level usually maintained.

If any further questions, please call.

Yours truly,

E. K. Heaney

EKH/cp

INSTALLATION RECOMMENDATIONS

PIPING SYSTEMS

Anaconda Expansion Joints must be both **correctly selected** and **properly installed** for effective performance in service. The reactions created by pressure and movement within the piping system should be carefully considered. The deflection loads and other influencing forces, including pressure thrust, must be recognized when designing anchors and guides. The internal pressure acting on the thrust area of an expansion joint can cause very high anchor loads. Thrust areas of Anaconda Expansion Joints are listed in the chart below. The following precautions must be taken during installation:

- System arrangement **must not create torque** on Expansion Joints.
- Piping centerlines should be **precisely aligned** for axial movement.
- Lateral movement should be **divided equally** on each side of the normal pipe centerline wherever possible.
- Anchors must be of **sufficient strength** to withstand the thrust pressure of the pipe section (thrust area of the Expansion Joint x maximum pressure).
- At initial system pressurization, all pipe guides and anchors must be **secure and functioning.**
- Field pressure tests should be **limited to 1.25 x the maximum working pressure** to avoid accidental over-pressurization.
- All shipping rods must be **removed.**

BELLOWS DIMENSIONAL DATA

PIPE SIZE IN INCHES	MAX. BELLOWS O.D. IN INCHES	THRUST AREA SQ. IN.	PIPE SIZE IN INCHES	MAX. BELLOWS O.D. IN INCHES	THRUST AREA SQ. IN.
2	3¼	5.5	12	14⅛	135
2½	3¾	7.5	14	16⅛	181
3	4⅜	10.5	16	18⅛	233
3½	4⅞	13.5	18	20⅛	289
4	5⅜	17	20	22⅝	347
5	6½	27	24	26⅝	492
6	7⅝	37	30	32⅝	755
8	9⅝	62	36	38⅝	1070
10	12	97	42	44⅝	1460
			48	50⅝	1885

INITIAL EXPANSION JOINT PURCHASE WAS ANACONDA 8" WITH SPECIAL CUFFS. SUBSEQUENT FLEXONICS ORDER REQUIRED THAT THE EXPANSION JOINT HAVE THE SAME I.D., O.D. AND WALL THICKNESS. THRUST AREA WILL BE THE SAME FOR EITHER EXPANSION JOINT.

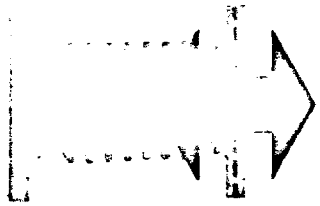
ANACONDA

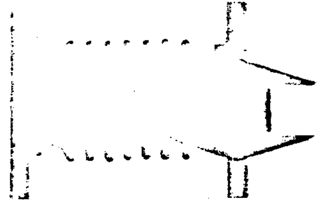
SHORT STYLE EXPANSION JOINTS

SERIES ES, MS

PIPE SIZE IN.	SERIES	MAXIMUM WORKING PRESSURE AT ROOM TEMPERATURE — FLANGED UNITS	NIPPLED UNITS (SEE NOTE 1)	FIXED FLANGES — TYPES ES44, MS44 — OAL IN.	APPROX. WT. LBS.	FLOATING FLANGES — TYPES ES77, MS77 — OAL IN.	APPROX. WT. LBS.	WELDING NIPPLES — TYPES ES11, MS11 — OAL IN.	APPROX. WT. LBS.
2	ES	120	120	6¼	11	—	—	6⅞	1.5
2½	ES	120	120	7⅛	15	—	—	7½	2.2
3	ES	120	120	7⅝	17	—	—	8⅞	4.0
3½	ES	120	120	7¾	23	—	—	8⅞	4.6
4	ES	150	120	7⅝	17	7⅝	16	9⅝	5.4
4	MS	300	240	8¼	28	8¼	29	9⅝	6.7
5	ES	130	100	8	22	8	22	10	7.3
5	MS	260	200	8⅞	34	8⅞	34	10	9.0
6	ES	100	80	8⅞	28	8⅞	28	10⅜	9.4
6	MS	200	160	9½	42	9½	39	10⅜	11
8	ES	100	80	10⅛	40	10⅛	37	12⅝	17
8	MS	200	160	11⅛	68	11⅛	64	12⅝	21
10	ES	80	80	10⅛	56	10⅛	53	12⅝	23
10	MS	160	160	11½	94	11½	89	12⅝	27
12	ES	80	70	10⅛	91	10⅛	88	12⅝	31
12	MS	160	140	12	142	12	138	12⅝	35
14	ES	60	50	11⅜	106	11⅜	97	14⅞	27
14	MS	120	100	11⅜	114	11⅜	106	14⅞	35
16	ES	50	45	11⅜	126	11⅜	127	14⅞	31
16	MS	100	90	11⅜	135	11⅜	137	14⅞	40
18	ES	50	40	12¼	130	12¼	131	15¾	36
18	MS	100	80	12¼	142	12¼	144	15¾	48
20	ES	40	30	10¾	149	10¾	150	14¼	37
20	MS	80	60	10¾	160	10¾	162	14¼	48
24	ES	40	25	11¾	239	—	—	14¼	44
24	MS	80	50	11¾	252	—	—	14¼	57
30	ES	40	24	(SEE NOTE 2)		—	—	14¼	56
30	MS	80	48			—	—	14¼	72
36	ES	35	20			—	—	14¼	67
36	MS	70	40			—	—	14¼	86
42	ES	30	18			—	—	14¼	78
42	MS	60	36			—	—	14¼	100
48	ES	25	15			—	—	14¼	89
48	MS	50	30			—	—	14¼	114

NOTES: 1. Nippled units can be provided to equal pressure capabilities of flanged units.
2. Details for sizes above 24" vary depending on flanges used. See Page 4.





AXIAL APPLICATION DATA . . .						LATERAL APPLICATION DATA . . .					
MAXIMUM RATED TOTAL AXIAL MOVEMENT IN INCHES FOR DESIGNATED CYCLE LIFE (SEE NOTE 1)						MAXIMUM RATED TOTAL LATERAL MOVEMENT IN INCHES FOR DESIGNATED CYCLE LIFE			FORCE IN POUNDS REQUIRED TO ACHIEVE LATERAL DEFLECTION IN INCHES FROM NORMAL CENTERLINE		
PIPE SIZE IN.	SERIES	AXIAL DEFLECTION FORCE LBS. PER IN.	FOR 1,000 CYCLES	FOR 7,000 CYCLES	FOR 15,000 CYCLES	FOR 1,000 CYCLES (See note 2)	FOR 7,000 CYCLES	FOR 15,000 CYCLES	.10"	.20"	.30"
2	ES	360	0.9	0.6	0.5	0.50	0.31	0.25	68	107	141
2½	ES	590	0.9	0.6	0.5	0.49	0.30	0.25	108	171	224
3	ES	530	1.1	0.7	0.6	0.52	0.32	0.26	111	176	232
3½	ES	600	1.1	0.7	0.6	0.46	0.29	0.24	154	245	322
4 4	ES MS	625 1250	1.2	0.7	0.6	0.44	0.27	0.23	181 362	286 572	378 756
5 5	ES MS	490 980	1.3	0.8	0.7	0.44	0.27	0.23	177 354	279 558	370 740
6 6	ES MS	525 1050	1.6	1.0	0.8	0.48	0.30	0.25	225 450	354 708	468 936
8 8	ES MS	457 914	2.0	1.2	1.0	0.59	0.36	0.29	205 410	323 626	427 854
10 10	ES MS	450 900	2.3	1.4	1.2	0.53	0.33	0.27	316 632	500 1,000	660 1,320
12 12	ES MS	420 840	2.8	1.7	1.4	0.55	0.34	0.28	404 808	635 1,270	840 1,680
14 14	ES MS	650 1300	2.9	1.8	1.5	0.58	0.35	0.29	648 1,296	1,020 2,040	1,350 2,700
16 16	ES MS	740 1480	2.9	1.8	1.5	0.51	0.31	0.26	940 1,880	1,480 2,960	1,960 3,920
18 18	ES MS	750 1500	3.2	2.0	1.6	0.56	0.34	0.28	963 1,926	1,520 3,040	2,010 4,020
20 20	ES MS	430 860	2.5	1.8	1.5	0.36	0.22	0.18	1,300 2,600	2,050 4,100	2,720 5,440
24 24	ES MS	520 1040	2.5	1.8	1.5	0.30	0.18	0.15	1,970 3,940	3,090 6,180	— —
30 30	ES MS	665 1330	2.5	1.8	1.5	0.24	0.15	0.12	3,460 6,720	5,440 10,900	— —
36 36	ES MS	800 1600	2.5	1.8	1.5	0.20	0.12	0.10	5,870 11,700	9,250 18,500	— —
42 42	ES MS	940 1880	2.5	1.8	1.5	0.17	0.11	0.09	9,160 18,300	14,440 28,900	— —
48 48	ES MS	1090 2180	2.5	1.8	1.5	0.15	0.09	0.08	15,150 30,300	— —	— —

NOTES: 1. See "Movements — Axial Travel", Page 5.
2. Total travel must be distributed. See "Movements — Lateral Travel", Page 5.

ALLOWABLE WORKING PRESSURES

For the convenience of piping engineers, pages 99 thru 109 show the allowable pressure rating at temperature of various piping materials including Stainless Steel Type 304L, 304, 316L, 316 and Monel, Nickel and Aluminum Alloys 3003 and 6061 in sizes ½" thru 24" in popular wall schedules.

Stress values shown at various temperatures are as given in Appendix A of ANSI B31.3—Code for Pressure Piping for Petroleum Refinery Piping.

The allowable pressure ratings have been calculated from the basic formula given in ANSI B31.3 as follows:

$$t = \frac{PD}{2S + 2yp} + C$$

or

$$p = \frac{2S\,(t - C)}{D - 2y\,(t - C)}$$

Where: t = design thickness of the pipe (12½% less than the nominal wall thickness of any given pipe size)

p = internal design pressure, PSIG

d = outside diameter of pipe, inches

s = allowable stress for materials at service temperature, psi

c = allowance for mechanical and corrosion, inches. (Zero for our calculations).

y = a coefficient having values as follows:

For austenitic stainless steels—
- 0.4 up to and including 1050°F.
- 0.5 for 1100°F
- 0.7 for 1150°F and above

For non ferrous metals—
- 0.4 up to and including 900°F.

The computations shown are a preliminary guide for determining the proper wall thickness and are not to be considered a substitute for various Codes for Pressure Piping.

The user should refer to the applicable Code for Pressure Piping covering the design and material limitations and rules. The particular Code should be reviewed before final design thickness is determined. Depending upon the general service for which the piping system is intended, one of the following may be applicable:

ASME—Section I—Power Boilers
ASME—Section III—Nuclear Power Plant Components
ASME—Section VIII—Pressure Vessels
ANSI B31.1—Power Piping
ANSI B31.3—Petroleum Refinery Piping
ANSI B31.5—Refrigeration Piping

The user is cautioned that the stress values shown in the various Codes do vary. For example, the stress values used in our calculations are not the same as noted in ANSI B31.1. Limitations on maximum temperature for materials may also vary with each Code.

It should be noted that all calculations are based on a specific piping material. Other materials may be used in the manufacture of **FLOWLINE** butt weld fittings. **FLOWLINE** fittings are so manufactured that their pressure ratings will equal or exceed those of equivalent straight pipe for the same size, wall thickness and material.

(continued on next page)

APPENDIX A
TABLE 1

ALLOWABLE STRESSES IN TENSION FOR MATERIALS (16, 46)
(NUMBERS IN PARENTHESES REFER TO STRESS TABLE NOTES. SEE PAGES 98 THROUGH 101)

Material	Specification	(37) "P" No.	Grade	Class	Factor (E)	Tensile Strength Min. PSI	Yield Strength Min. PSI	Notes	(26) Min. Temp.	Temp. To 100	200	300
STAINLESS STEEL (40) (4)												
Seamless Pipe and Tubes												
26Cr-3Ni-1Mo Tubes	ASTM A268	10E	TP329			90000	70000	28	−20	30000		
12Cr-Al Tubes	ASTM A268	7	TP405			60000	30000	28	−20	20000	19100	18400
11Cr-Ti Tubes	ASTM A268	6	TP409			60000	30000	28	−20	20000		
13Cr Tubes	ASTM A268	6	TP410			60000	30000	28	−20	20000	19100	18400
16Cr Tubes	ASTM A268	7	TP430			60000	35000	28, 38	−20	20000	19100	18400
18Cr-Ti Tubes	ASTM A268	7	TP430-1			60000	30000	28, 38	−20	20000		
20Cr-Cu Tubes	ASTM A268	10	TP443			70000	40000	28	−20	23350	22350	21400
27Cr-Tubes	ASTM A268	10E	TP446			70000	40000	28	−20	23350	22350	21400
18Cr-8Ni Pipe	ASTM A312	8	TP304			75000	30000	6a, 20, 23, 30	−425	20000	20000	20000
18Cr-8Ni Pipe	ASTM A312	8	TP304H			75000	30000	23	−325	20000	20000	20000
18Cr-8Ni Pipe	ASTM A312	8	TP304L			70000	25000		−425	16650	16650	16650
23Cr-12Ni Pipe	ASTM A312	8	TP309			75000	30000	28, 41, 52	−325	20000	20000	20000
25Cr-20Ni Pipe	ASTM A312	8	TP310			75000	30000	28, 41, 52	−325	20000	20000	20000
25Cr-20Ni Pipe	ASTM A312	8	TP310			75000	30000	6, 28, 41, 52	−325	20000	20000	20000
16Cr-12Ni-2Mo Pipe	ASTM A312	8	TP316			75000	30000	20	−325	20000	20000	20000
16Cr-12Ni-2Mo Pipe	ASTM A312	8	TP316H			75000	30000	23	−325	20000	20000	20000
16Cr-12Ni-2Mo Pipe	ASTM A312	8	TP316L			70000	25000		−325	16650	16650	16650
18Cr-13Ni-3Mo Pipe	ASTM A312	8	TP317			75000	30000	20, 23	−325	20000	20000	20000
18Cr-10Ni-Ti Pipe	ASTM A312	8	TP321			75000	30000	6a, 20	−325	20000	20000	20000
18Cr-10Ni-Ti Pipe	ASTM A312	8	TP321H			75000	30000		−325	20000	20000	20000
18Cr-10Ni-Cb Pipe	ASTM A312	8	TP347			75000	30000	6a, 20	−425	20000	20000	20000
18Cr-10Ni-Cb Pipe	ASTM A312	8	TP347H			75000	30000		−325	20000	20000	20000
18Cr-10Ni-Cb Pipe	ASTM A312	8	TP348			75000	30000	6a, 20	−325	20000	20000	20000
18Cr-10Ni-Cb Pipe	ASTM A312	8	TP348H			75000	30000		−325	20000	20000	20000
18Cr-8Ni Pipe	ASTM A376	8	TP304			75000	30000	6b, 20, 23, 30, 36	−425	20000	20000	20000
18Cr-8Ni Pipe	ASTM A376	8	TP304H			75000	30000	23	−325	20000	20000	20000
16Cr-12Ni-2Mo Pipe	ASTM A376	8	TP316			75000	30000	6b, 20, 23, 36	−325	20000	20000	20000
16Cr-12Ni-2Mo Pipe	ASTM A376	8	TP316H			75000	30000	23	−325	20000	20000	20000
18Cr-10Ni-Ti Pipe	ASTM A376	8	TP321			75000	30000	6a, 20, 36	−325	20000	20000	20000
18Cr-10Ni-Ti Pipe	ASTM A376	8	TP321H			75000	30000		−325	20000	20000	20000
18Cr-10Ni-Cb Pipe	ASTM A376	8	TP347			75000	30000	6a, 20, 36	−425	20000	20000	20000
18Cr-10Ni-Cb Pipe	ASTM A376	8	TP347H			75000	30000		−325	20000	20000	20000
18Cr-10Ni-Cb Pipe	ASTM A376	8	TP348			75000	30000	6a, 20, 36	−325	20000	20000	20000
16Cr-8Ni-2Mo Pipe	ASTM A376	8	16-8-2H			75000	30000	6b, 23, 12	−325	20000		
18Cr-8Ni Pipe	ASTM A430	8	FP304			70000	30000	6b, 23, 36	−425	20000	20000	20000
18Cr-8Ni Pipe	ASTM A430	8	FP304H			70000	30000	23, 36	−325	20000	20000	20000
16Cr-12Ni-2Mo Pipe	ASTM A430	8	FP316			70000	30000	6b, 23, 36	−325	20000	20000	20000
16Cr-12Ni-2Mo Pipe	ASTM A430	8	FP316H			70000	30000	23, 36	−325	20000	20000	20000
18Cr-10Ni-Ti Pipe	ASTM A430	8	FP321			70000	30000	6a, 36	−325	20000	20000	20000
18Cr-10Ni-Ti Pipe	ASTM A430	8	FP321H			70000	30000	36	−325	20000	20000	20000
18Cr-10Ni-Cb Pipe	ASTM A430	8	FP347			70000	30000	6a, 36	−425	20000	20000	20000
18Cr-10Ni-Cb Pipe	ASTM A430	8	FP347H			70000	30000	36	−325	20000	20000	20000
16Cr-8Ni-2Mo Pipe	ASTM A430	8	FP-16-8-2H			70000	30000	6b, 23, 36	−325	20000		
Centrifugally Cast Pipe												
18Cr-8Ni	ASTM A451	8	CPF8		0.90	70000	28000	20, 22, 23	−425	16800	16800	16800
18Cr-10Ni-2Mo	ASTM A451	8	CPF8M		0.90	70000	30000	20, 22, 23	−425	18000	18000	18000
18Cr-10Ni-Cb	ASTM A451	8	CPF8C		0.90	70000	30000	6a, 20, 22	−325	18000	18000	18000
15Cr-13Ni-2Mo-Cb	ASTM A451	8	CPF10MC		0.90	70000	30000	6a, 12, 20, 22	−325	18000		
23Cr-13Ni	ASTM A451	8	CPH8		0.90	65000	28000	12, 20, 22, 28	−325	16800	16800	16800
23Cr-13Ni	ASTM A451	8	CPH10 or CPH20		0.90	70000	30000	8, 12, 20, 22, 28, 41	−325	18000	18000	18000
25Cr-20Ni	ASTM A451	8	CPK20		0.90	65000	28000	20, 22, 28, 41	−325	16800	16800	16800
18Cr-8Ni	ASTM A452	8	TP304H		0.85	75000	30000	22, 23	−325	17000	17000	17000
16Cr-12Ni-2Mo	ASTM A452	8	TP316H		0.85	75000	30000	22, 23	−325	17000	17000	17000
18Cr-10Ni-Cb	ASTM A452	8	TP347H		0.85	75000	30000	22	−325	17000	17000	17000
Electric Fusion Welded Pipe and Tubes												
12Cr-Al Tubes	ASTM A268	7	TP405		0.85	60000	30000	28	−20	17000	16250	15650
11Cr-Ti Tubes	ASTM A268	6	TP409		0.85	60000	30000	28	−20	17000		
13Cr Tubes	ASTM A268	6	TP410		0.85	60000	30000	28	−20	17000	16250	15650
16Cr Tubes	ASTM A268	7	TP430		0.85	60000	35000	28, 38	−20	17000	16250	15650
18Cr-Ti Tubes	ASTM A268	7	TP430-1		0.85	60000	30000	28, 38	−20	17000		
20Cr-Cu Tubes	ASTM A268	10	TP443		0.85	70000	40000	28	−20	19850	19850	18200
27Cr Tubes	ASTM A268	10E	TP446		0.85	70000	40000	28	−20	19850	19850	18200
26Cr-3Ni-1Mo Tubes	ASTM A268	10E	TP329		0.85	90000	70000	28	−20	25500		
18Cr-8Ni Pipe	ASTM A312	8	TP304		0.85	75000	30000	20, 23	−425	17000	17000	17000
18Cr-8Ni Pipe	ASTM A312	8	TP304H		0.85	75000	30000	23	−325	17000	17000	17000
18Cr-8Ni Pipe	ASTM A312	8	TP304L		0.85	70000	25000		−425	14200	14200	14200
23Cr-12Ni Pipe	ASTM A312	8	TP309		0.85	75000	30000	28, 41, 52	−325	17000	17000	17000
25Cr-20Ni Pipe	ASTM A312	8	TP310		0.85	75000	30000	28, 41, 52	−325	17000	17000	17000
25Cr-20Ni Pipe	ASTM A312	8	TP310		0.85	75000	30000	6, 28, 41, 52	−325	17000	17000	17000
16Cr-12Ni-2Mo Pipe	ASTM A312	8	TP316		0.85	75000	30000	20, 23	−325	17000	17000	17000
18Cr-12Ni-2Mo Pipe	ASTM A312	8	TP316H		0.85	75000	30000	23	−325	17000	17000	17000
16Cr-12Ni-2Mo Pipe	ASTM A312	8	TP316L		0.85	70000	25000		−325	14200	14200	14200
18Cr-13Ni-3Mo Pipe	ASTM A312	8	TP317		0.85	75000	30000	20, 23	−325	17000	17000	17000
18Cr-10Ni-Ti Pipe	ASTM A312	8	TP321		0.85	75000	30000	6a, 20	−325	17000	17000	17000
18Cr-10Ni-Ti Pipe	ASTM A312	8	TP321H		0.85	75000	30000		−325	17000	17000	17000
18Cr-10Ni-Cb Pipe	ASTM A312	8	TP347		0.85	75000	30000	6a, 20	−425	17000	17000	17000
18Cr-10Ni-Cb Pipe	ASTM A312	8	TP347H		0.85	75000	30000		−325	17000	17000	17000
18Cr-10Ni-Cb Pipe	ASTM A312	8	TP348		0.85	75000	30000	6a, 20	−325	17000	17000	17000
18Cr-10Ni-Cb Pipe	ASTM A312	8	TP348H		0.85	75000	30000		−325	17000	17000	17000
Type 304 A240	ASTM A358	8	304	2	0.85	75000	30000	6b, 20, 23, 36	−425	17000	17000	17000

For shaded areas see Note 4

APPENDIX A

TABLE 1

ALLOWABLE STRESSES IN TENSION FOR MATERIALS (16, 46)

(NUMBERS IN PARENTHESES REFER TO STRESS TABLE NOTES. SEE PAGES 98 THROUGH 101)

Material	Specification	(37) "P" No.	Grade	Class	Factor (E)	Tensile Strength Min. PSI	Yield Strength Min. PSI	Notes	(26) Min. Temp.	Min. Temp. To 100	200	300
CARBON STEEL (Cont.)												
Castings												
	ASTM A216	1	WCA		0.80	60000	30000	2, 9, 22	-20	16000	14650	14150
	ASTM A216	1	WCB		0.80	70000	36000	2, 9, 22	-20	18650	17500	17350
	ASTM A216	1	WCC		0.80	70000	40000	2, 9, 22	-20	18650	18650	18650
	ASTM A352	1	LCB		0.80	65000	35000	2, 9, 22	-50	17350	17050	16550
Structural												
NOTE: Materials such as pipe, castings, forgings, etc., listed elsewhere in Appendix A may also be used as structural materials.												
	ASTM A36	1			0.92	58000	36000	2, 5, 34	-20	‖ 17800	16900	16900
LOW AND INTERMEDIATE ALLOY STEEL												
Seamless Pipe												
3½ Ni	ASTM A333	9B	3			65000	35000		−150	21700	19600	19600
3½ Ni	ASTM A334	9B	3			65000	35000		−150	21700	19600	19600
Ni-Cr Cu-Al	ASTM A333	4	4			60000	35000		−150	20000	19100	18150
2¼ Ni	ASTM A333	9A	7			65000	35000		−100	21700	19600	19600
2¼ Ni	ASTM A334	9A	7			65000	35000		−100	21700	19600	19600
9 Ni	ASTM A333	11A-SG1	8			100000	75000	69	−320	31700	31700	
9 Ni	ASTM A334	11A-SG1	8			100000	75000	69	−320	31700	31700	
2 Ni-1 Cu	ASTM A333	9A	9			63000	46000		−100	21000		
2 Ni-1 Cu	ASTM A334	9A	9			63000	46000		−100	21000		
c-½ Mo	ASTM A335	3	P1			55000	30000	3	−20	18300	18300	18100
½ Cr-½ Mo	ASTM A335	3	P2			55000	30000	3	−20	18300	18300	18100
5 Cr-½ Mo	ASTM A335	5	P5			60000	30000		−20	20000	18200	17300
5 Cr-½ Mo-1½ Si	ASTM A335	5	P5b			60000	30000		−20	20000	18200	17300
5 Cr-½ Mo	ASTM A335	5	P5c			60000	30000		−20	20000	18200	17300
7CR-½ Mo	ASTM A335	5	P7			60000	30000		−20	20000	18200	17300
9 Cr-1 Mo	ASTM A335	5	P9			60000	30000		−20	20000	18200	17300
1¼ Cr-½ Mo	ASTM A335	4	P11			60000	30000		−20	20000	18700	18000
1 Cr-½ Mo	ASTM A335	4	P12			60000	30000	3	−20	20000	18700	18000
1½ Si-½ Mo	ASTM A335	3	P15			60000	30000	3	−20	18750	18150	17600
3 Cr-1 Mo	ASTM A335	5	P21			60000	30000		−20	20000	18700	18000
2¼ Cr-1 Mo	ASTM A335	5	P22			60000	30000		−20	20000	18700	18000
C-½ Mo	ASTM A369	3	FP1			55000	30000	3	−20	18300	18300	18100
½ Cr-½ Mo	ASTM A369	3	FP2			55000	30000	3	−20	18300	18300	18100
2 Cr-½ Mo	ASTM A369	4	FP3b			60000	30000		−20	20000	18700	18000
5 Cr-½ Mo	ASTM A369	5	FP5			60000	30000		−20	20000	18200	17300
7 Cr-½ Mo	ASTM A369	5	FP7			60000	30000		−20	20000	18200	17300
9 Cr-1 Mo	ASTM A369	5	FP9			60000	30000		−20	20000	18200	17300
1¼ Cr-½ Mo	ASTM A369	4	FP11			60000	30000		−20	20000	18700	18000
1 Cr-½ Mo	ASTM A369	4	FP12			60000	30000	3	−20	20000	18700	18000
3 Cr-1 Mo	ASTM A369	5	FP21			60000	30000		−20	20000	18700	18000
2¼ Cr-1 Mo	ASTM A369	5	FP22			60000	30000		−20	20000	18700	18000
Centrifugally Cast Pipe												
C-½ Mo	ASTM A426	3	CP1		1.00	65000	35000	3, 21	−20	21700	21700	21700
½ Cr-½ Mo	ASTM A426	3	CP2		1.00	55000	30000	3, 21	−20	18350	17650	16950
5 Cr-½ Mo	ASTM A426	5	CP5		1.00	90000	60000	21	−20	30000	25000	26050
5 Cr-½ Mo-1½ Si	ASTM A426	5	CP5b		1.00	60000	30000	21	−20	18750	17900	17050
7 Cr-½ Mo	ASTM A426	5	CP7		1.00	60000	30000	21	−20	18750	17850	17000
9 Cr-1 Mo	ASTM A426	5	CP9		1.00	90000	60000	21	−20	30000	22500	22500
1¼ Cr-½ Mo	ASTM A426	4	CP11		1.00	70000	40000	21	−20	23300	23300	23300
1 Cr-½ Mo	ASTM A426	4	CP12		1.00	60000	30000	3, 21	−20	18750	18250	17600
1½ Si-½ Mo	ASTM A426	3	CP15		1.00	60000	30000	3, 21	−20	18750	18150	17600
12¼ Cr	ASTM A426	7	CPCA-15		1.00	90000	65000	21	−20	30000		
3 Cr-1 Mo	ASTM A426	5	CP21		1.00	60000	30000	21	−20	18750	18100	17400
2¼ Cr-1 Mo	ASTM A426	5	CP22		1.00	70000	40000	21	−20	23300	23300	23300
Electric Resistance Welded Pipe												
3½ Ni Pipe	ASTM A333	9B	3		0.85	65000	35000		−150	18400	16700	16700
2¼ Ni Pipe	ASTM A333	9A	7		0.85	65000	35000		−100	18400	16700	16700
9 Ni Pipe	ASTM A333	11A	8		0.85	100000	75000		−320	28300	28300	
2 Ni-1 Cu Pipe	ASTM A333		9		0.85	63000	46000		−100	17850		
Electric Fusion Welded Pipe												
C-Mo A204 GR A	ASTM A155	3	CM65	2	0.85	65000	37000	3	−20	18450	18450	18450
C-Mo A204 GR B	ASTM A155	3	CM70	2	0.85	70000	40000	3	−20	19800	19800	19800
C-Mo A204 GR C	ASTM A155	3	CM75	2	0.85	75000	43000	3	−20	21250	21250	21250
½Cr-½Mo A 387 GR2 CL1	ASTM A155	3	½ Cr	2	0.85	55000	33000	3	−20	15550	15550	15550
1Cr-½Mo A 387 GR 12 CL1	ASTM A155	4	1 Cr	2	0.85	55000	33000	3	−20	15550	15550	15550
1¼Cr-½Mo A 387 GR11 CL1	ASTM A155	4	1¼ Cr	2	0.85	60000	35000		−20	17000	17000	17000
2¼Cr-1Mo A387 GR22 CL1	ASTM A155	5	2¼ Cr	2	0.85	60000	30000		−20	17000	15900	15300
5Cr-½Mo A387 GR5 CL1	ASTM A155	5	5 Cr	2	0.85	60000	30000		−20	17000	15450	14700
C-Mo A204 GR A	ASTM A155	3	CM65	3	0.90	65000	37000	3, 17	−20	19550	19550	19550
C-Mo A204 GR B	ASTM A155	3	CM70	3	0.90	70000	40000	3, 17	−20	20950	20950	20950
C-Mo A204 GR C	ASTM A155	3	CM75	3	0.90	75000	43000	3, 17	−20	22500	22500	22500
½Cr-½Mo A387 GR2 CL1	ASTM A155	3	½ Cr	3	0.90	55000	33000	3, 17	−20	16450	16450	16450
1Cr-½Mo A387 GR12 CL1	ASTM A155	4	1 Cr	3	0.90	55000	33000	3, 17	−20	16450	16450	16450
1¼Cr-½Mo A387 GR11 CL1	ASTM A155	4	1¼ Cr	3	0.90	60000	35000	17	−20	18000	18000	18000
2¼Cr 1Mo A387 GR22 CL1	ASTM A155	5	2¼ Cr	3	0.90	60000	30000	17	−20	18000	16850	16200
5Cr-½Mo A387 GR5 CL1	ASTM A155	5	5 Cr	3	0.90	60000	30000	17	−20	18000	16400	15550
C-Mo A204 GR A	ASTM A155	3	CM65	3	1.00	65000	37000	3	−20	21700	21700	21700
C-Mo A204 GR B	ASTM A155	3	CM70	3	1.00	70000	40000	3	−20	23300	23300	23300
C-Mo A204 GR C	ASTM A155	3	CM75	3	1.00	75000	43000	3	−20	25000	25000	25000
½Cr-½Mo A387 GR 2 CL1	ASTM A155	3	½ Cr	3	1.00	55000	33000	3	−20	18300	18300	18300
1Cr ½Mo A387 GR 12 CL1	ASTM A155	4	1 Cr	1	1.00	55000	33000	3	−20	18300	18300	18300
1¼Cr ½Mo A387 GR 11 CL1	ASTM A155	4	1¼ Cr	1	1.00	60000	35000		−20	20000	20000	20000
2¼Cr 1Mo A387 GR 22 CL1	ASTM A155	5	2¼ Cr	1	1.00	60000	30000		−20	20000	18700	18000
5Cr-½Mo A387 GR 5 CL1	ASTM A155	5	5 Cr	1	1.00	60000	30000		−20	20000	18200	17300
2¼Ni A203 GR B	ASTM A671	9A	CF 70	10 or 20	0.85	70000	40000	66, 67	−20	19700	17900	

TABLE 1

ALLOWABLE STRESSES IN TENSION FOR MATERIALS (16, 46)

(NUMBERS IN PARENTHESES REFER TO STRESS TABLE NOTES. SEE PAGES 98 THROUGH 101)

Material	Specification	(37) "P" No.	Grade	Class	Factor (E)	Tensile Strength Min. PSI	Yield Strength Min. PSI	Notes	(26) Min. Temp.	Min. Temp. To 100	200	300
CARBON STEEL (Cont.)												
Electric Fusion Welded Pipe (Straight Seam) (Cont.)												
	API 5L	1	A		0.85	48000	30000	1, 2	-20	13600	13600	13600
	API 5L	1	B		0.85	60000	35000	1, 2	-20	17000	17000	17000
	API 5LX	SP2	X42		0.85	60000	42000	58, 60	-20	17000	17000	17000
	API 5LX	SP3	X46		0.85	63000	46000	58, 60	-20	17850	17850	17850
	API 5LX	SP3	X52		0.85	66000	52000	58, 60	-20	18700	18700	18700
	API 5LX	SP3	X52		0.85	72000	52000	58, 60	-20	20400	20400	20400
A537 GR C1.1	ASTM A155			2	0.85	70000	50000		-20	19800	19800	19500
	ASTM A155			3	0.90	70000	50000		-20	21000	21000	20600
	ASTM A155			1	1.00	70000	50000		-20	23300	23300	22900
Spiral Welded Pipe												
A570 GR A	ASTM A134	1			0.74	45000	25000	5, 34	-20	11050	10550	
A570 GR B	ASTM A134	1			0.74	49000	30000	5, 34	-20	12000	11450	
A570 GR C	ASTM A134	1			0.74	52000	33000	5, 34	-20	12750	12150	
A570 GR D	ASTM A134	1			0.74	55000	40000	5, 34	-20	13500	12850	
A570 GR E	ASTM A134	1			0.74	58000	42000	5, 34	-20	14200	13650	
A611 GR A	ASTM A134	1			0.74	42000	25000	5, 35	-20	10300	9850	
A611 GR B	ASTM A134	1			0.74	45000	30000	5, 34	-20	11000	10500	
A611 GR C	ASTM A134	1			0.74	48000	33000	5, 34	-20	11800	11200	
A611 GR D	ASTM A134	1			0.74	52000	40000	5, 34	-20	12750	12150	
A283 GR A	ASTM A134	1			0.74	45000	24000	5, 34	-20	11050	10550	
A283 GR B	ASTM A134	1			0.74	50000	27000	5, 34	-20	12250	11650	
A283 GR C	ASTM A134	1			0.74	55000	30000	5, 34	-20	13500	12900	
A283 GR D	ASTM A134	1			0.74	60000	33000	5, 34	-20	14750	14000	
A285 GR A	ASTM A134	1			0.80	45000	24000	34	-20	12000	11700	
A285 GR B	ASTM A134	1			0.80	50000	27000	34	-20	13350	13100	
A285 GR C	ASTM A134	1			0.80	55000	30000	34	-20	14650	14650	
	ASTM A139	1	A		0.80	48000	30000	34	-20	12800	12800	
	ASTM A139	1	B		0.80	60000	35000	34	-20	16000	16000	
	ASTM A139	1	C		0.80	60000	42000	34	-20	16000	16000	
	ASTM A139	1	D		0.80	60000	46000	34	-20	16000	16000	
	ASTM A139	1	E		0.80	66000	52000	34	-20	17600	17600	
A570 GR A	ASTM A211	1			0.69	45000	25000	5, 34	-20	10300	10000	
A570 GR B	ASTM A211	1			0.69	49000	30000	5, 34	-20	11000	10700	
A570 GR C	ASTM A211	1			0.69	52000	33000	5, 34	-20	11900	11500	
A570 GR D	ASTM A211	1			0.69	55000	40000	5, 34	-20	12600	12050	
	API 5LS	1	A		0.85	48000	30000	58	-20	13600	13600	
	API 5LS	1	B		0.85	60000	35000	58	-20	17000	17000	
Plates & Sheets												
Sheets	ASTM A570	1	A		0.92	45000	25000	2, 5	-20	13800	13300	12800
Sheets	ASTM A570	1	B		0.92	49000	30000	2, 5	-20	15000	14300	13650
Sheets	ASTM A570	1	C		0.92	52000	33000	2, 5	-20	15950	15200	14500
Sheets	ASTM A570	1	D		0.92	55000	40000	2, 5	-20	16800	16100	15500
Sheets	ASTM A570	1	E		0.92	58000	42000	2, 5	-20	17800	16950	16350
Sheets	ASTM A611	1	A		0.92	42000	25000	2, 5	-20	12900	12400	11900
Sheets	ASTM A611	1	B		0.92	45000	30000	2, 5	-20	13800	13100	12550
Sheets	ASTM A611	1	C		0.92	48000	33000	2, 5	-20	14750	14100	13400
Sheets	ASTM A611	1	D		0.92	52000	40000	2, 5	-20	15900	15200	14600
Plates	ASTM A283	1	A		0.92	45000	24000	2, 5, 34	-20	13800	13200	12550
Plates	ASTM A283	1	B		0.92	50000	27000	2, 5, 34	-20	15300	14600	14000
Plates	ASTM A283	1	C		0.92	55000	30000	2, 5, 34	-20	16900	16100	15350
Plates	ASTM A283	1	D		0.92	60000	33000	2, 5, 34	-20	18400	17550	16750
Plates	ASTM A285	1	A			45000	24000	1, 2	-20	15000	14600	14200
Plates	ASTM A285	1	B			50000	27000	1, 2	-20	16700	16400	16000
Plates	ASTM A285	1	C			55000	30000	1, 2	-20	18300	18300	17700
Plates (< 1" Thick)	ASTM A299	3				75000	42000	2, 11	-20	25000	25000	24800
Plates (> 1" Thick)	ASTM A299	3				75000	40000	2	-20	25000	24400	23700
Plates	ASTM A515	1	55			55000	30000	2	-20	18300	18300	17700
Plates	ASTM A515	1	60			60000	32000	2	-20	20000	19500	18900
Plates	ASTM A515	1	65			65000	35000	2	-20	21700	21300	20700
Plates	ASTM A515	1	70			70000	38000	2	-20	23300	23100	22500
Plates	ASTM A516	1	55			55000	30000	2	-20	18300	18300	17700
Plates	ASTM A516	1	60			60000	32000	2	-20	20000	19500	18900
Plates	ASTM A516	1	65			65000	35000	2	-20	21700	21300	20700
Plates	ASTM A516	1	70			70000	38000	2	-20	23300	23100	22500
Plates	ASTM A537	1	C1.1			70000	50000		-20	23300	23300	22900
Forgings & Fittings												
Forgings & Fittings	ASTM A105	1				70000	36000	1, 2, 9	-20	23300	21900	21300
Forgings & Fittings	ASTM A181	1	I			60000	30000	1, 2, 9	-20	20000	18300	17700
Forgings & Fittings	ASTM A181	1	II			70000	36000	1, 2, 9	-20	23300	21900	21300
Fittings	ASTM A234	1	WPA			48000	30000	1, 2, 13	-20	16000	16000	16000
Fittings	ASTM A234	1	WPB			60000	35000	1, 2, 13	-20	20000	20000	20000
Fittings	ASTM A234	1	WPC			70000	40000	1, 2, 13	-20	23300	23300	23300
Forgings & Fittings	ASTM A350	1	LF-1			60000	30000	1, 2, 9, 70	-50	20000	18300	17700
Forgings & Fittings	ASTM A350	1	LF-2			70000	36000	2, 9	-50	23300	21900	21300
Forgings & Fittings	ASTM A420	1	WPL-6			60000	32000	2, 13	-50	20000	19500	18900

TABLE 1

ALLOWABLE STRESSES IN TENSION FOR MATERIALS (16, 46)

(NUMBERS IN PARENTHESES REFER TO STRESS TABLE NOTES. SEE PAGES 96 THROUGH 101)

Material	Specification	Grade	Class	Temper	(37) "P" No.	Size Range	Factor (E)	Tensile Strength Min. PSI	Yield Strength Min. PSI	Notes	(26) Min. Temp.	Min. Temp. To 100	150	200	250	300	350
ALUMINUM ALLOY																	
Seamless Pipes & Tubes																	
	ASTM B210	1060		0	21	0.010"-0.500"		8500	2500	43	-452	1600	1600	1600	1400	1200	1000
	ASTM B241	1060		0	21	All		8500	2500	43	-452	1600	1600	1600	1400	1200	1000
	ASTM B210	1060		H112	21	0.010"-0.500"		8500	2500	15, 43	-452	1600	1600	1600	1400	1200	1000
	ASTM B241	1060		H112	21	All		8500	2500	15, 43	-452	1600	1600	1600	1400	1200	1000
	ASTM B210	1060		H14	21	0.010"-0.500"		12000	10000	15, 43	-452	3000	3000	3000	2900	2600	1800
	ASTM B210	3003		0	21	0.010"-0.500"		14000	5000	43	-452	3300	3300	3300	3200	2400	1800
	ASTM B241	3003		0	21	All		14000	5000	43	-452	3300	3300	3300	3200	2400	1800
	ASTM B210	3003		H14	21	0.010"-0.500"		20000	17000	15, 43	-452	5000	5000	5000	4800	4300	3000
	ASTM B210	3003		H18	21	0.010"-0.500"		27000	24000	15, 43	-452	6700	6700	6600	6300	5300	3500
	ASTM B210	3003		H112	21	0.050"-0.500"		13000	4500	15, 43	-452	3000	3000	3000	2900	2400	1800
	ASTM B241	3003		H112	21	All		14000	5000	15, 43	-452	3300	3300	3300	3200	2400	1800
	ASTM B210	3003 CLAD		0	21	0.010"-0.500"		13000	4500	43	452	3000	3000	3000	2900	2100	1600
	ASTM B241	3003 CLAD		0	21	All		13000	4500	43	-452	3000	3000	3000	2900	2100	1600
	ASTM B210	3003 CLAD		H112	21	0.050"-0.500"		13000	4500	15, 43	-452	3000	3000	3000	2700	2100	1600
	ASTM B241	3003 ALCLAD		H112	21	All		13000	4500	15, 43	-452	3000	3000	3000	2900	2100	1600
	ASTM B210	3003 CLAD		H14	21	0.010"-0.500"		19000	16000	15, 43	-452	4500	4500	4500	4300	3800	2700
	ASTM B210	3003 CLAD		H18	21	0.010"-0.500"		26000	23000	15, 43	-452	6100	6100	6000	5600	4800	3100
	ASTM B210	5050		0	21			18000	6000	43	-452	4000	4000	4000	4000	4000	3350
	ASTM B210	5052		0	22	0.018"-0.450"		25000	10000	43	-452	6200	6200	6200	6200	5600	4100
	ASTM B241	5052		0	22	All		25000	10000	43	-452	6200	6200	6200	6200	5600	4100
	ASTM B210	5083		0	25			39000	16000	43	-452	10650					
	ASTM B241	5083		0	25	Up thru 5.000"		39000	16000	43	-452	9700	9700				
	ASTM B241	5083		H112	25	Up thru 5.000"		39000	16000	15, 43	-452	9700	9700				
	ASTM B210	5086		0	25			35000	14000	43	-452	9350	9150				
	ASTM B210	5086		H32	25			40000	28000	15, 43	-452	13300	9900				
	ASTM B210	5086		H34	25			44000	34000	15, 43	-452	14650	10800				
	ASTM B210	5154		0	22	0.018"-0.450"		30000	11000	43	-452	7300	7300				
	ASTM B210	5154		H34	22	0.018"-0.450"		39000	29000	15, 43	-452	9700	9700				
	ASTM B210	5456		0	25			41000	19000	43	-452	12700					
	ASTM B241	5456		0	25	Up thru 5.000"		41000	19000	43	-452	10200	10200				
	ASTM B210	6061		T4	23	0.025"-0.500"		30000	16000	15, 43	-452	10000	10000	10000	9800	9200	
	ASTM B241	6061		T4	23	All		26000	16000	15, 43	-452	8600	8600	8600	8500	7900	
	ASTM B210	6061		T6	23	0.025"-0.500"		42000	35000	15, 43	-452	14000	14000	14000	13400	11300	
	ASTM B241	6061		T6	23	All		38000	35000	15, 43	-452	12600	12600	12600	12200	10500	
	ASTM B210	6061		Welded	23			24000		15, 50	-452	6000	5900	5700	5400	5000	4200
	ASTM B241	6061		Welded	23			24000		15, 50	-452	6000	5900	5700	5400	5000	4200
	ASTM B210	6063		T4	23			22000	10000	15, 43	-452	6650	5100	4900	4600	4150	3100
	ASTM B210	6063		T6	23	0.025"-0.500"		33000	28000	15, 43	-452	11000	11000	10500	9500	7000	
	ASTM B241	6063		T6	23	Up thru 1.000"		30000	25000	15, 43	-452	10000	10000	9800	9000	6600	
	ASTM B210	6063		Welded	23			17000		15	-452	4250	4200	4000	3800	3600	2750
	ASTM B241	6063		Welded	23			17000		15	-452	4250	4200	4000	3800	3600	2750
Structural																	
	ASTM B221	1060		0	21	All		8500	2500	43	-452	1600	1600	1600	1400	1200	1000
	ASTM B221	1060		H112	21	All		8500	2500	15, 43	-452	1600	1600	1600	1400	1200	1000
	ASTM B221	3003		0	21	All		14000	5000	43	-452	3300	3300	3300	3200	2400	1800
	ASTM B221	3003		H112	21	All		14000	5000	15, 43	-452	3300	3300	3300	3200	2400	1800
	ASTM B221	3003 CLAD		0	21			13000	4500	43	-452	3000	3000	3000	2950	2200	1950
	ASTM B221	3003 CLAD		H112	21			13000	4500	15, 43	-452	3000	3000	3000	2950	2200	1950
	ASTM B221	5052		0	22			25000	10000	43	-452	6650	6250	6200	6000	5400	4650
	ASTM B221	5083		0	25	Up thru 5.000"		39000	16000	43	-452	9700	9700				
	ASTM B221	5154		0	22	All		30000	11000	43	-452	7300	7300				
	ASTM B221	5456		0	25			41000	19000	43	-452	12700					
	ASTM B221	6061		T4	23	All		26000	16000	15, 43	-452	8600	8600	8600	8500	7900	
	ASTM B221	6061		T6	23	All		38000	35000	15, 43	-452	12600	12600	12600	12200	10500	
	ASTM B221	6061		Welded	23			24000		15, 50	-452	6000	5900	5700	5400	5000	4200
	ASTM B221	6063		T4	23			18000	9000	15, 43	-452	6000					
	ASTM B221	6063		T6	23	Up thru 1.000"		30000	25000	15, 43	-452	10000	10000	9800	9000	6600	
	ASTM B221	6063		Welded	23			17000		15	-452	4250	4200	4000	3800	3600	2750
Plates & Sheets																	
	ASTM B209	1060		0	21	0.051"-3.000"		8000	2500	43	-452	1600	1600	1600	1400	1200	1000
	ASTM B209	1060		H112	21	1.001"-3.000"		9000	4000	11, 15, 43	-452	2200	2100	1900	1700	1400	1000
	ASTM B209	1060		H12	21	0.051"-2.000"		11000	9000	15, 43	-452	2700	2700	2600	2300	2000	1800
	ASTM B209	1060		H14	21	0.051"-1.000"		12000	10000	15, 43	-452	3000	3000	3000	2900	2600	1800
	ASTM B209	1100		0	21	0.051"-3.000"		11000	3500	43	-452	2300	2300	2300	2200	1700	1300
	ASTM B209	1100		H112	21	2.0" MaxTh		12000	5000	11, 15, 43	-452	3000	3000	2800	2500	2200	1600
	ASTM B209	1100		H12	21	0.051"-2.000"		14000	11000	15, 43	-452	3500	3500	3500	3200	2800	1900
	ASTM B209	1100		H14	21	0.051"-1.000"		16000	14000	15, 43	-452	4000	4000	4000	3600	2800	1900
	ASTM B209	3003		0	21	0.051"-3.000"		14000	5000	43	-452	3300	3300	3300	3200	2400	1800
	ASTM B209	3003		H112	21	2.001"-3.000"		14500	6000	11, 15, 43	-452	4000	4000	3900	3800	2400	1800
	ASTM B209	3003		H12	21	0.051"-2.000"		17000	12000	15, 43	-452	4200	4200	4200	3900	3600	3000
	ASTM B209	3003		H14	21	0.051"-1.000"		20000	17000	15, 43	-452	5000	5000	5000	4800	4300	3000
	ASTM B209	3003 CLAD		0	21	0.051"-0.499"		13000	4500	11, 43	-452	3000	3000	3000	2700	2100	1600
	ASTM B209	3003 CLAD		H112	21	2.001"-3.000"		14500	6000	11, 15, 43	-452	3200	3200	3100	2900	2100	1600
	ASTM B209	3003 CLAD		H12	21	0.051"-0.499"		16000	11000	11, 15, 43	-452	3800	3800	3800	3400	3200	2700
	ASTM B209	3003 CLAD		H14	21	0.051"-0.499"		19000	16000	11, 15, 43	-452	4500	4500	4500	4300	3800	2700
	ASTM B209	3004		0	22	0.051"-3.000"		22000	8500	43	-452	5600	5600	5600	5600	5000	3800
	ASTM B209	3004		H112	22	0.250"-3.000"		23000	9000	15, 43	-452	6000	6000	6000	6000	5100	3800
	ASTM B209	3004		H32	22	0.051"-2.000"		28000	21000	15, 43	-452	7000	7000	7000	7000	5700	3800
	ASTM B209	3004		H34	22	0.051"-1.000"		32000	25000	15, 43	-452	8000	8000	8000	8000	5700	3800
	ASTM B209	3004 CLAD		0	22	0.051"-0.499"		21000	8000	11, 43	-452	4900	4900	4900	4900	4500	3400
	ASTM B209	3004 CLAD		H112	22	0.250"-0.499"		22000	8500	11, 15, 43	-452	5200	5200	5200	5200	4600	3400
	ASTM B209	3004 CLAD		H32	22	0.051"-0.499"		27000	20000	11, 15, 43	-452	6300	6300	6300	6300	5200	3400
	ASTM B209	3004 CLAD		H34	22	0.051"-0.499"		31000	24000	11, 15, 43	-452	7200	7200	7200	7200	5200	3400
	ASTM B209	5050		0	21	0.051"-3.000"		18000	6000	43	-452	4000	4000	4000	4000	4000	3400

APPENDIX A
TABLE 1

ALLOWABLE STRESSES IN TENSION FOR MATERIALS (16, 46)

(NUMBERS IN PARENTHESES REFER TO STRESS TABLE NOTES. SEE PAGES 98 THROUGH 101)

Material	Specification	(37) "P" No.	Grade	Class	Factor (E)	Tensile Strength Min. PSI	Yield Strength Min. PSI	Note	(26) Min. Temp.	Min. Temp. To 100	200	300
AINLESS STEEL (4) (40) (Cont.)												
Electric Fusion Welded Pipe and Tubes (Cont.)												
Type 316 A240	ASTM A358	8	316	2	0.85	75000	30000	6b, 20, 23, 36	-325	17000	17000	17000
Type 347 A240	ASTM A358	8	347	2	0.85	75000	30000	6a, 20, 36	-425	17000	17000	17000
Type 321 A240	ASTM A358	8	321	2	0.85	75000	30000	6a, 20, 36	-325	17000	17000	17000
Type 309S A240	ASTM A358	8	309S	2	0.85	75000	30000	6b, 28, 36, 52	-325	17000	17000	17000
Type 310S A240	ASTM A358	8	310S	2	0.85	75000	30000	28, 36, 52	-325	17000	17000	17000
Type 310S A240	ASTM A358	8	310S	2	0.85	75000	30000	6, 28, 36, 52	-325	17000	17000	17000
Type 348 A240	ASTM A358	8	348	2	0.85	75000	30000	6a, 20, 36	-325	17000	17000	17000
Type 304 A240	ASTM A358	8	304		0.90	75000	30000	6b, 17, 20, 23, 36	-425	18000	18000	18000
Type 316 A240	ASTM A358	8	316		0.90	75000	30000	6b, 17, 20, 23, 36	-325	18000	18000	18000
Type 347 A240	ASTM A358	8	347		0.90	75000	30000	6a, 17, 20, 36	-425	18000	18000	18000
Type 321 A240	ASTM A358	8	321		0.90	75000	30000	6a, 17, 20, 36	-325	18000	18000	18000
Type 309S A240	ASTM A358	8	309S		0.90	75000	30000	6b, 17, 28, 36, 52	-325	18000	18000	18000
Type 310S A240	ASTM A358	8	310S		0.90	75000	30000	17, 28, 36, 52	-325	18000	18000	18000
Type 310S A240	ASTM A358	8	310S		0.90	75000	30000	6, 17, 28, 36, 52	-325	18000	18000	18000
Type 348 A240	ASTM A358	8	348		0.90	75000	30000	6a, 17, 20, 36	-325	18000	18000	18000
Type 304 A240	ASTM A358	8	304	1	1.00	75000	30000	6b, 20, 23, 36	-425	20000	20000	20000
Type 316 A240	ASTM A358	8	316	1	1.00	75000	30000	6b, 20, 23, 36	-325	20000	20000	20000
Type 347 A240	ASTM A358	8	347	1	1.00	75000	30000	6a, 20, 36	-425	20000	20000	20000
Type 321 A240	ASTM A358	8	321	1	1.00	75000	30000	6a, 20, 36	-325	20000	20000	20000
Type 309 A240	ASTM A358	8	309S	1	1.00	75000	30000	6a, 28, 36, 52	-325	20000	20000	20000
Type 310S A240	ASTM A358	8	310S	1	1.00	75000	30000	28, 36, 52	-325	20000	20000	20000
Type 310S A240	ASTM A358	8	310S	1	1.00	75000	30000	6, 28, 36, 52	-325	20000	20000	20000
Type 348 A240	ASTM A358	8	348	1	1.00	75000	30000	6a, 20, 36	-325	20000	20000	20000
18Cr-8Ni Pipe	ASTM A409	8	TP304		0.85	75000	30000	6b, 20, 23, 36	-425	17000	17000	17000
23Cr-12Ni Pipe	ASTM A409	8	TP309		0.85	75000	30000	6b, 28, 36, 41, 52	-325	17000	17000	17000
25Cr-20Ni Pipe	ASTM A409	8	TP310		0.85	75000	30000	6b, 28, 36, 41, 52	-325	17000	17000	17000
18Cr-10Ni-Ti Pipe	ASTM A409	8	TP321		0.85	75000	30000	6a, 20, 36	-325	17000	17000	17000
18Cr-10Ni-Cb Pipe	ASTM A409	8	TP347		0.85	75000	30000	6a, 20, 36	-425	17000	17000	17000
16Cr-12Ni-2Mo Pipe	ASTM A409	8	TP316		0.85	75000	30000	6b, 20, 23, 36	-325	17000	17000	17000
18Cr-13Ni-3Mo Pipe	ASTM A409	8	TP317		0.85	75000	30000	6b, 20, 23, 36	-325	17000	17000	17000
18Cr-10Ni-Cb Pipe	ASTM A409	8	TP348		0.85	75000	30000	6a, 20, 36	-325	17000	17000	17000
Plates and Sheets												
16Cr-6Ni	ASTM A167	8	301			75000	30000	6b, 12, 23	-325	20000	16650	15000
18Cr-8Ni	ASTM A167	8	302			75000	30000	6b, 12, 20, 23	-325	20000	20000	20000
18Cr-8Ni	ASTM A167	8	302B			75000	30000	6b, 12, 20, 23	-325	20000	20000	20000
18Cr-8Ni	ASTM A167	8	304			75000	30000	6b, 20, 23, 36	-425	20000	20000	20000
18Cr-8Ni	ASTM A167	8	304L			70000	25000	36	-425	16650	16650	16650
8Cr-10Ni	ASTM A167	8	305			70000	25000	6b, 12, 23	-325	16700		
20Cr-10Ni	ASTM A167	8	308			75000	30000	6b, 23, 36	-325	20000	16650	15000
23Cr-12Ni	ASTM A167	8	309			75000	30000	6b, 12, 28, 52	-325	20000	20000	20000
23Cr-12Ni	ASTM A167	8	309S			75000	30000	6b, 28, 36, 52	-325	20000	20000	20000
25Cr-20Ni	ASTM A167	8	310			75000	30000	12, 28, 52	-325	20000	20000	20000
25Cr-20Ni	ASTM A167	8	310			75000	30000	6, 12, 28, 52	-325	20000	20000	20000
25Cr-20Ni	ASTM A167	8	310S			75000	30000	6b, 28, 36, 52	-325	20000	20000	20000
16Cr-12Ni-2Mo	ASTM A167	8	316			75000	30000	6b, 20, 23, 36	-325	20000	20000	20000
16Cr-12Ni-2Mo	ASTM A167	8	316L			70000	25000	36	-325	16650	16650	16650
18Cr-13Ni-3Mo	ASTM A167	8	317			75000	30000	6b, 20, 23, 36	-325	20000	20000	20000
18CR-13Ni-3Mo	ASTM A167	8	317L			75000	30000	36	-325	20000	20000	20000
18Cr-10Ni-Ti	ASTM A167	8	321			75000	30000	6a, 20, 36	-325	20000	20000	20000
18Cr-10Ni-Cb	ASTM A167	8	347			75000	30000	6a, 20, 36	-425	20000	20000	20000
18Cr-10Ni-Cb	ASTM A167	8	348			75000	30000	6a, 20, 36	-325	20000	20000	20000
18Cr-8Ni	ASTM A240	8	302			75000	30000	6b, 12, 20, 23	-325	20000	20000	20000
18Cr-8Ni	ASTM A240	8	304			75000	30000	6b, 20, 23, 36	-425	20000	20000	20000
18Cr-8Ni	ASTM A240	8	304L			70000	25000	6b, 36	-425	16650	16650	16650
18Cr-10Ni	ASTM A240	8	305			70000	25000	6b, 12, 23	-325	16700		
23Cr-12Ni	ASTM A240	8	309S			75000	30000	6b, 28, 36, 52	-325	20000	20000	20000
25Cr-20Ni	ASTM A240	8	310S			75000	30000	6b, 28, 36, 52	-325	20000	20000	20000
16Cr-12Ni-2Mo	ASTM A240	8	316			75000	30000	6b, 20, 23, 36	-325	20000	20000	20000
16Cr-12Ni-2Mo	ASTM A240	8	316L			70000	25000	36	-325	16650	16650	16650
18Cr-13Ni-3Mo	ASTM A240	8	317			75000	30000	6b, 20, 23, 36	-325	20000	20000	20000
18Cr-13Ni-3Mo	ASTM A240	8	317L			75000	30000	36	-325	20000	20000	20000
18Cr-10Ni-Ti	ASTM A240	8	321			75000	30000	6a, 20, 36	-325	20000	20000	20000
18Cr-10Ni-Cb	ASTM A240	8	347			75000	30000	6a, 20, 36	-425	20000	20000	20000
18Cr-10Ni-Cb	ASTM A240	8	348			75000	30000	6a, 20, 36	-325	20000	20000	20000
12Cr-Al	ASTM A240	7	405			60000	25000	28	-20	16700	15900	15400
13Cr	ASTM A240	6	410			65000	30000	28	-20	20000	19100	18400
13Cr	ASTM A240	7	410S			60000	30000	28, 31	-20	20000	19100	18400
15Cr	ASTM A240	6	429			65000	30000	28	-20	20000	19100	18400
17Cr	ASTM A240	7	430			65000	30000	28	-20	20000	19100	18400
18Cr-Ti-Al	ASTM A240		XM8			65000	30000	28	-20	20000		
Forgings and Seamless Fittings												
18Cr-8Ni	ASTM A182	8	F304			75000	30000	9, 20, 23, 32	-425	20000	20000	20000
18Cr-8Ni	ASTM A182	8	F304H			75000	30000	9, 23, 32	-325	20000	20000	20000
18Cr-8Ni	ASTM A182	8	F304L			65000	25000	9	-425	16650	16650	16650
25Cr-20Ni	ASTM A182	8	F310			75000	30000	9, 28, 41, 52	-425	20000	20000	20000
25Cr-20Ni	ASTM A182	8	F310			75000	30000	6, 9, 28, 41, 52	-425	20000	20000	20000
16Cr-12Ni-2Mo	ASTM A182	8	F316			75000	30000	9, 20, 23, 32	-325	20000	20000	20000
16Cr-12Ni-2Mo	ASTM A182	8	F316H			75000	30000	9, 23, 32	-325	20000	20000	20000
16Cr-12Ni-2Mo	ASTM A182	8	F316L			65000	25000	9	-325	16650	16650	16650
18Cr-10Ni-Ti	ASTM A182	8	F321			75000	30000	6a, 9, 20, 32, 36	-325	20000	20000	20000
18Cr-10Ni-Ti	ASTM A182	8	F321H			75000	30000	9, 32	-325	20000	20000	20000

For shaded areas see Note 4

STAINLESS STEEL BUTT-WELDING FITTINGS

FOREWORD

ANSI B16.9 is the American Standard for steel but-welding fittings and although not so stated, it is implied that its scope deals primarily with the schedules of wall thicknesses which are common to carbon steel and the grades of alloy steel piping that are selected for pressure and temperature considerations.

The rapid expansion of the process industries in the field of chemicals, plastics, textiles, etc. has created a demand for a class of pipe referred to as stainless piping, using this word in its generic sense. This field employs the use of the austenitic stainless steels and also nickel and its related alloys. This stainless piping is used with resistance to corrosion, elimination of product contamination, or combination of the two as the principle reason for material selection. Pressure is seldom, if ever, a critical consideration.

When pressure is a consideration reference is made to ANSI B16.9.

Mechanical strength, resistance to vacuum, and economy, are the most usual criteria in the selection of pipe thickness in this field for this reason, the wall thicknesses employed in the field of corrosion resistant pipe are lighter than those in common usage with carbon steel piping.

In 1949 ANSI approved standard B36.19 Stainless Steel Pipe in which a schedule of wall thickness was established and designated as Schedule 10S for sizes 3/4 in. inclusive. Numerous companies were also using a wall thickness lighter than Schedule 10S for services where contamination rather than corrosion was the prime consideration. These lighter wall thicknesses were designated Schedule 5S and the original 1950 edition of SP-43 established a series of Schedule 5S fittings. The 5S thicknesses were published in SP-43 and were developed in cooperation with representatives of the various principal chemical companies and processing industries. In 1952 the Stainless Steel Pipe Standard B36.19 was revised to recognize the Schedule 5S wall thickness pipe as American Standard.

The purpose of this standard is to provide industry with a set of dimensional standards for butt-welding fittings that can be used with these light wall pipes of corrosion resisting materials. The center-to-end dimensions of all fittings are identical with those in ANSI B16.9 which give to industry the advantage of uniform design room practice and a maximum utilization of existing die equipment. The only departure from this is in the lap-joint stub end where for purposes of economy the face-to-end of the product has been reduced for use with thin wall piping.

The advantages of longer center-to-end dimensions of the size 3/4 elbows resulted in the change in the tables to permit a gradual change-over, providing the manufacturers ample time to deplete existings stocks, re-tool and replenish stocks.

An MSS Standard Practice is intended as a basis for common practice by the manufacturer, the user, and the general public. The existence of an MSS Standard Practice does not in itself preclude the manufacture, sale, or use of products not conforming to the Standard Practice. Mandatory conformance is established only by reference in a code, specification, sales contract, or public law.

WROUGHT STAINLESS STEEL BUTT-WELDING FITTINGS

1. SCOPE

1.1 This standard covers overall dimensions, tolerances, and markings for wrought stainless steel butt-welding fittings. In this standard "wrought" is used to denote fittings made of pipe, tubing, plate, bar, sheet, strip or forgings.

1.2 This standard covers only fittings made for use with Schedule 5S or 10S pipe as given in ANSI B36.19, except that short pattern stub ends suitable for use with Schedule 40S are also shown.

1.3 Annex A. Table A1 lists the dimensions of stainless steel pipe with which these fittings are intended to be used.

2. PRESSURE RATINGS

2.1 Fittings produced under this standard shall carry the following ratings: (Schedule 5S piping is not recommended for use at temperatures above 400F (200C).

Temp	PSI	
F	10S	5S
100	275	225
150	255	215
200	240	200
250	225	190
300	210	175
350	195	165
400	180	150
450	165	–
500	150	–
550	140	–
600	130	–
650	120	–
700	110	–
750	100	–

Temp	Bars	
C	10S	5S
38	18.9	15.5
50	18.3	15.2
100	16.3	13.6
125	15.4	12.9
150	14.4	12.0
175	13.5	11.4
200	12.6	10.5
225	11.6	
250	10.7	
275	9.9	
300	9.3	
325	8.7	
350	8.1	
375	7.5	
400	6.8	

2.2 Fabricated Tees employing intersection welds shall be considered in this standard and shall be rated at 70% of these ratings.

2.3 For fittings of same pressure rating of matching pipe, refer to ANSI B16.9.

3. SIZE

The size of the fittings in Tables 1 through 6 and B1 through B6, and Annex A is identified by the corresponding nominal pipe size.

4. MARKING

4.1 Each fitting shall be marked to show the following:

a) Manufacturer's name or trademark
b) "CR" followed by the material (identification symbol established for the respective grade in the appropriate ASTM or AISI specifications).

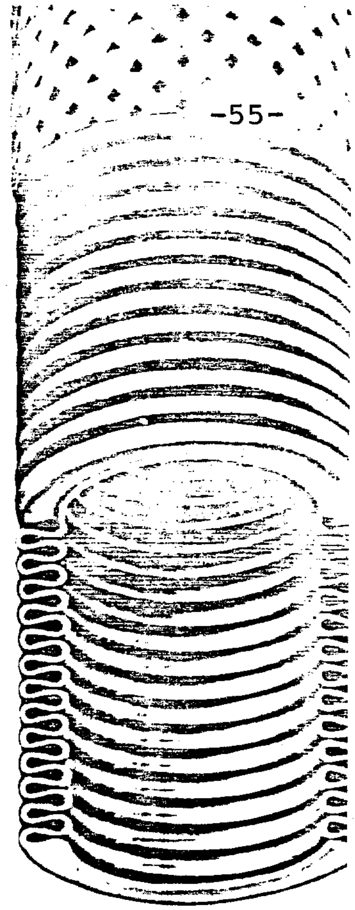
(STD. 2" SCH 10 WELD NIPPLE END FITTING) △A

NOTES:

1. FLEX IS 316L STAINLESS STEEL, ANNULAR CORRUGATED, CLOSED PITCH, BUTT WELDED METAL HOSE WITH A CONVOLUTE WALL THICKNESS OF .006" TO .008" AND ONE COVER OF 304 STAINLESS STEEL WIRE BRAID
I.D. TO BE $2" \pm \frac{1}{8}$ O.D. TO BE $2\frac{1}{2}" \pm \frac{1}{4}$
2. SERVICE : HELIUM GAS & VACUUM
3. OPERATING PRESSURE RANGE : -14.7_{psig} TO 100_{psig}
4. OPERATING TEMP. RANGE : −320°F TO 100°F
5. ALL WELDS TO BE MADE WITH INTERNAL ARGON GAS PURGE. △A
6. ASSEMBLIES TO BE MASS SPEC. LEAK TIGHT TO 10^{-4} ATM-CC/SEC HELIUM
7. FLANGE FACE ON ITEM #3 (O-RING SEALING SURFACE) TO BE PROTECTED FROM DAMAGE DURING FABRICATION & SHIPMENT. △A

FLEXONICS FLEX HOSE

5	[illegible]
4	[illegible]
3	MA
2	MA
1	[illegible]
ITEM	[illegible]



FLEX-WELD BUTT-WELDED ANNULAR CORRUGATED HOSE

1. Maximum Working Pressure — Maximum pressure hose may be subjected to during operation. Based on 25% of the Rated Burst Pressure.
2. Maximum Test Pressure — Maximum pressure hose may be subjected to for inspection. Based on 150% of the Maximum Working Pressure.
3. Rated Burst Pressure — Pressure at which hose may fail. Burst pressures published in this catalog were obtained with the hose at 70°, installed straight, and subjected to a constantly increasing pressure.

FLEX-WELD STAINLESS STEEL (FWSS)

Construction	Butt-welded annular corrugated metal hose.
*Size Range	¼" thru 16" I.D.
Rated Burst Pressure	Up to 15,000 PSIG, depending on size and temperature
Temperature	Up to 1500° F.—321 S.ST. Up to 1000° F.—316-L S.ST. Up to 1000° F.—304-L S.ST. Up to 1000° F.—Perma-Hose

FLEX-WELD BRONZE (FWB)

Construction	Butt-welded annular corrugate metal hose.
*Size Range	¼" thru 6" I.D.
Rated Burst Pressure	Up to 4,200 PSIG, depending on size and temperature
Temperature	Up to 450° F.

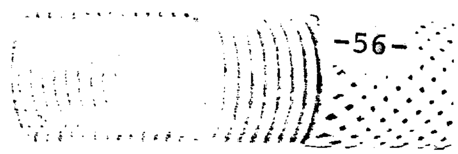
FLEX-WELD CARBON STEEL (FWCS)

Construction	Butt-welded annular corrugated metal hose.
*Size Range	¼" thru 12" I.D.
Rated Burst Pressure	Up to 5,200 PSIG, depending on size and temperature
Temperature	Up to 850° F.

FLEX-WELD MONEL (FWM)

Construction	Butt-welded annular corrugatec metal hose.
*Size Range	¼" thru 10" I.D.
Rated Burst Pressure	Up to 9,000 PSIG, depending on size and temperature
Temperature	Up to 800° F.

* Larger sizes available on application.



FLEX-WELD
[illegible]
ANNULAIR
CORRUGATED
HOSE

BUTT-WELDED STAINLESS STEEL

Light weight Type 321 and Type 316*.
Other grades available on application.

FWSST-30— Unbraided
FWSST-31— Single Braided

STAINLESS STEEL • LIGHT WEIGHT

Nominal Hose I.D. Inches	Product Number	Approx. Weight Per Ft. Lbs.	Nominal Hose O.D. Inches	Min. C. L Bend Radius for: Inter-mittent Flexing	Min. C. L Bend Radius for: Static Bend	Maximum Working Pressure @ 70° P.S.I.G.: Silver Brazed	Maximum Working Pressure @ 70° P.S.I.G.: Welded	Maximum Test Pressure @ 70° P.S.I.G.: Silver Brazed	Maximum Test Pressure @ 70° P.S.I.G.: Welded	Rated Burst Pressure @ 70° P.S.I.G.: Silver Brazed	Rated Burst Pressure @ 70° P.S.I.G.: Welded
¾	FWSST-30 FWSST-31	.30 .42	1.20 1.26	7 7	2 2	32 875	32 700	42 1300	42 1050	3500	2800
1	FWSST-30 FWSST-31	.35 .52	1.35 1.41	8 8	2½ 2½	26 675	26 575	36 1000	36 860	2700	2300
1¼	FWSST-30 FWSST-31	.44 .67	1.67 1.73	8¾ 8¾	3 3	20 550	20 450	30 825	30 675	2200	1800
1½	FWSST-30 FWSST-31	.62 .94	2.00 2.07	9¾ 9¾	3½ 3½	14 500	14 400	24 750	24 600	2000	1600
2	FWSST-30 FWSST-31	.76 1.16	2.50 2.57	10 10	4½ 4½	10 450	10 350	20 675	20 525	1800	1400
2½	FWSST-30 FWSST-31	1.50 2.07	3.22 3.28	14 14	7 7	10 450	10 325	20 675	20 475	1800	1300
3	FWSST-30 FWSST-31	1.65 2.45	3.74 3.82	16 16	8 8	8 400	8 300	16 600	16 450	1600	1200
3½	FWSST-30 FWSST-31	1.90 2.70	4.30 4.38	19 19	9½ 9½	8 375	8 250	16 550	16 375	1500	1000
4	FWSST-30 FWSST-31	2.20 3.10	4.81 4.89	24 24	10½ 10½	6 350	6 225	15 525	15 325	1400	950
5	FWSST-30 FWSST-31	3.00 4.70	6.00 6.13	26 26	13 13	4 250	4 200	15 375	15 300	1100	800
6	FWSST-30 FWSST-31	3.20 4.90	6.90 7.03	28 28	14 14	3 200	3 175	15 300	15 250	1000	700

*Type 316 available on application.
Refer to page 4 for explanation of pressure ratings. For higher pressure requirements, contact FLEX-WELD, INC.
NOTE: Refer to page 12 for elevated temperature correction factors and live length required for offset or lateral motion. For pulsating or shock pressure applications, consult FLEX-WELD engineers. Larger sizes available on application.

LAP-WELDED STAINLESS STEEL

Type 321 and Type 316*.

FLWSS-30 — Unbraided
FLWSS-31 — Single Braided

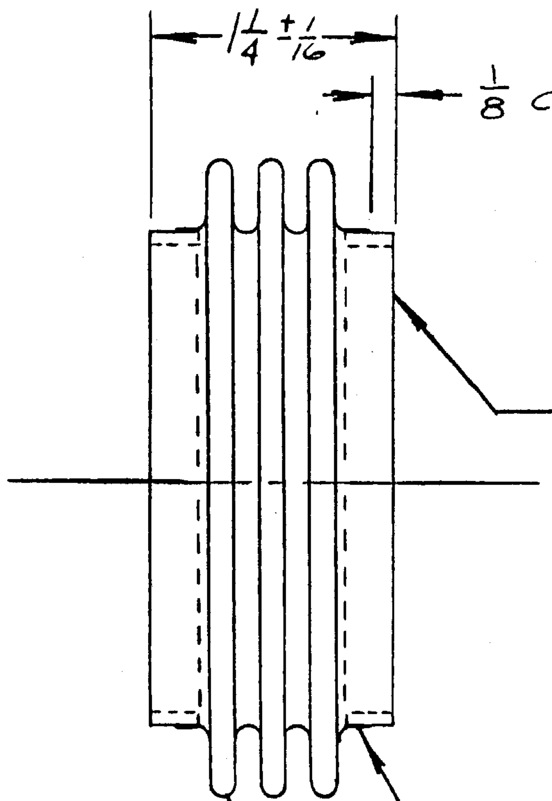
STAINLESS STEEL

	Nominal Hose I.D. Inches	Product Number	Approx. Weight Per Ft. Lbs.	Nominal Hose O.D. Inches	Min. C/L Bend Radius for: Intermittent Flexing	Min. C/L Bend Radius for: Static Bend	Maximum Working Pressure @ 70° P.S.I.G.	Maximum Test Pressure @ 70° P.S.I.G.	Rated Burst Pressure 70° P.S.I.G.
	1	FLWSS-30 FLWSS-31	.17 .29	1.31 1.37	5 5	2½ 2½	550	825	2200
	1¼	FLWSS-30 FLWSS-31	.27 .50	1.62 1.68	6 6	3 3	525	785	2100
	1½	FLWSS-30 FLWSS-31	.35 .67	1.93 2.00	7 7	3½ 3½	475	615	1900
DIPOLE	2	FLWSS-30 FLWSS-31	.48 .88	2.50 2.56	8 8	4 4	375	560	1500
	2½	FLWSS-30 FLWSS-31	.55 1.12	3.00 3.06	13 13	6 6	300	450	1200
Spud	3	FLWSS-30 FLWSS-31	.62 1.42	3.50 3.56	14 14	7 7	250	375	1000
	4	FLWSS-30 FLWSS-31	1.10 2.20	4.75 4.81	15 15	7½ 7½	185	275	750
	6	FLWSS-30 FLWSS-31	1.80 3.50	6.92 6.98	19 19	9 9	135	200	550

*Type 316 available on application
Refer to page 4 for explanation of pressure ratings. For higher pressure requirements, contact FLEX-WELD, INC.
NOTE: Refer to page 12 for elevated temperature correction factors and live length required for offset or lateral motion. For pulsating or shock pressure applications, consult FLEX-WELD engineers. Larger sizes available on application.

REV.	DESCRIPTION	DRAWN / APPD.	DATE
A	REDRAWN	JRM	

FLEXONICS
& FLEXWELD
ALIGNMENT FLEX



$\frac{1}{8}$ CLEAR OF WELD REGION - TYPICAL

WELD CUFFS $\frac{1}{4}$" LONG $\frac{1}{16}$" THICK
$2\frac{13}{32}$ I.D. 316 L ST. STL.
TYP BOTH ENDS

VAC TIGHT
TYPICAL

.014 $\pm$.002 WALL 316 L
STAINLESS STEEL
O.D. $3\frac{1}{4} \pm \frac{1}{4}$
I.D. $2\frac{1}{2} \pm \frac{1}{16}$
NUMBER OF CONVOLUTES — AS REQ'D

NOTES:
1. SPRING RATE —
2000 TO 3000 LB/IN
2. SERVICE TEMP —
-320° F
3. SERVICE PRESSURE —
100 PSIG

UNLESS OTHERWISE SPECIFIED			ORIGINATOR		
FRACTIONS	DECIMALS	ANGLES	DRAWN	J MILLER	1/23/81
± 1/64	± ~	± ~	CHECKED		
1. BREAK ALL SHARP EDGES 1/64 MAX. 2. DO NOT SCALE DWG. 3. DIMENSIONING IN ACCORD WITH ANSI Y14.5 STD. 250 MAX. ALL MACHINED SURFACES			APPROVED		
			USED ON	—	
			MATERIAL-	—	

FERMI NATIONAL ACCELERATOR LABORATORY
U.S. DEPARTMENT OF ENERGY

ENERGY SAVER
MAGNET RELIEF FLEX
QUAD 1φ & 2φ - ALIGN. FLEX

SCALE	FILMED	DRAWING NUMBER	REV
FULL		0428 DD-MA-107165	A

Series 10C0 Bellows

Sizes — ¼″ through 48″ I.D.

MANUFACTURED WITH STANDARD TOOLING

321 Stainless Steel (other materials available on request)

CONVOLUTE LENGTH

PART NUMBER 1000 —	ID INCH	OD INCH	EFFECTIVE AREA	OPERATING PRESSURE	1000 CYCLES 2 INCH A	B	C	4 INCH A	B	C	6 INCH A	B	C	8 INCH A	B	C
0222 A	2.264	2.750	4.94	51	102	36	1.710	29	18	3.419	13	12	5.129	7	9	6.838
0222 B	2.264	2.750	4.94	73	146	63	1.425	50	31	2.849	22	21	4.274	12	15	5.699
0222 D	2.264	2.750	4.94	130	260	149	1.069	117	74	2.137	52	49	3.206	29	37	4.274
0222 E	2.264	2.750	4.94	203	406	292	.855	229	146	1.710	102	97	2.564	57	73	3.419
0222 G	2.264	2.750	4.94	293	586	504	.712	396	252	1.425	176	168	2.137	99	126	2.849
0222 J	2.264	2.750	4.94	457	914	985	.570	774	492	1.140	344	328	1.710	194	246	2.279
0223 A	2.287	2.790	5.06	47	94	58	1.041	46	29	2.081	20	19	3.122	12	14	4.162
0223 B	2.287	2.790	5.06	68	136	101	.867	80	50	1.734	35	33	2.601	20	25	3.468
0223 D	2.287	2.790	5.06	121	242	240	.650	189	120	1.301	84	80	1.951	47	60	2.602
0223 E	2.287	2.790	5.06	190	380	469	.520	369	234	1.041	164	156	1.561	92	117	2.081
0223 G	2.287	2.790	5.06	273	546	811	.433	546	405	.867	283	270	1.300	159	202	1.734
0223 J	2.287	2.790	5.06	427	854	1584	.347	854	792	.694	553	528	1.041	311	396	1.387
0223 L	2.287	2.790	5.06	615	1230	2737	.289	1230	1368	.578	956	912	.867	538	684	1.156
0231 A	2.375	3.000	5.67	31	62	27	1.860	22	13	3.720	10	9	5.580	5	6	7.440
0231 B	2.375	3.000	5.67	44	88	48	1.549	38	24	3.099	17	16	4.648	9	12	6.198
0231 D	2.375	3.000	5.67	79	158	114	1.162	90	57	2.325	40	38	3.487	22	28	4.650
0231 E	2.375	3.000	5.67	123	246	223	.930	176	111	1.860	78	74	2.790	44	55	3.720
0231 G	2.375	3.000	5.67	177	354	386	.775	304	193	1.550	135	128	2.325	76	96	3.101
0231 J	2.375	3.000	5.67	276	552	755	.620	552	377	1.240	264	251	1.860	148	188	2.480
0231 L	2.375	3.000	5.67	398	796	1304	.517	796	652	1.033	455	434	1.550	256	326	2.067
0241 A	2.400	3.080	5.90	26	52	24	1.992	19	12	3.984	9	8	5.977	5	6	7.969
0241 B	2.400	3.080	5.90	37	74	42	1.661	33	21	3.322	15	14	4.982	8	10	6.643
0241 D	2.400	3.080	5.90	66	122	100	1.245	79	50	2.491	35	33	3.736	20	25	4.981
0241 E	2.400	3.080	5.90	104	208	195	.996	154	97	1.992	68	65	2.988	38	48	3.984
0241 G	2.400	3.080	5.90	149	298	338	.830	266	169	1.660	118	112	2.490	66	84	3.320
0241 J	2.400	3.080	5.90	234	468	660	.664	468	330	1.328	231	220	1.992	130	165	2.656
0251 A	2.500	3.000	5.94	48	96	61	1.077	49	30	2.154	22	20	3.231	12	15	4.308
0251 B	2.500	3.000	5.94	69	138	106	.898	84	53	1.796	37	35	2.694	21	26	3.592
0251 D	2.500	3.000	5.94	123	246	253	.673	199	126	1.347	88	84	2.020	50	63	2.693
0251 E	2.500	3.000	5.94	192	384	494	.539	384	247	1.077	172	164	1.616	97	123	2.154
0251 G	2.500	3.000	5.94	276	552	853	.449	552	426	.897	298	284	1.346	168	213	1.795
0251 J	2.500	3.000	5.94	432	864	1667	.359	864	833	.718	582	555	1.077	327	416	1.436
0251 L	2.500	3.000	5.94	622	1244	2881	.299	1244	1440	.598	1006	960	.898	566	720	1.197
0252 A	2.500	3.000	5.94	48	96	51	1.300	40	25	2.599	18	17	3.899	10	12	5.198
0252 B	2.500	3.000	5.94	69	138	88	1.083	69	44	2.166	31	29	3.250	17	22	4.333
0252 D	2.500	3.000	5.94	123	246	209	.813	165	104	1.625	73	69	2.438	41	52	3.251
0252 E	2.500	3.000	5.94	192	384	409	.650	322	204	1.300	143	136	1.949	80	102	2.599
0252 G	2.500	3.000	5.94	276	552	707	.542	552	353	1.083	247	235	1.625	139	176	2.166
0252 J	2.500	3.000	5.94	432	864	1381	.433	864	690	.867	482	460	1.300	271	345	1.734
0253 A	2.500	3.200	6.38	24	48	24	2.015	19	12	4.030	9	8	6.045	5	6	8.061
0253 B	2.500	3.200	6.38	35	70	42	1.679	33	21	3.358	15	14	5.037	8	10	6.716
0253 D	2.500	3.200	6.38	63	126	100	1.260	79	50	2.520	35	33	3.779	20	25	5.039
0253 E	2.500	3.200	6.38	98	196	195	1.008	154	97	2.015	68	65	3.023	38	48	4.030
0253 G	2.500	3.200	6.38	141	282	337	.839	265	168	1.679	118	112	2.518	66	84	3.358
0253 J	2.500	3.200	6.38	220	440	659	.672	518	329	1.343	230	219	2.015	130	164	2.687
0253 L	2.500	3.200	6.38	317	634	1140	.560	896	570	1.120	398	380	1.679	224	285	2.239

SQUIRM PRESSURE

OPERATING PRESSURE

SPRING RATE

CORPORATION Post Office Box 180 • Newport, Rhode Island 02840 • Tel. 401-846-9100 • TWX 710-387-6921

 ALIGNMENT FLEX CONVOLUTE LENGTH = .66 IN. CORRECTION FOR 2″ $= \frac{2}{.66} = 3$

UNISTRUT

BEAM LOADS:

Allowable uniformly distributed loads are listed for various simple spans, that is, beam on two supports. If load is concentrated at center of span, multiply load from table by 0.5 and corresponding deflection by 0.8.

Stress 25,000 #/sq. in. — Recommended for use where deflection is not a factor on long spans.

Deflection 1/240 span — Recommended for use when deflection is a factor.

COLUMN LOADS:

Column loadings are for allowable axial loads for the unsupported heights listed. If loads are eccentric, loads should be reduced according to standard practice.

BEAM AND COLUMN DATA:

BEAM SPAN OR COLUMN UNSUPPORTED HEIGHT	SECTION NUMBER	UNIFORM LOAD AT 25,000 PSI STRESS	DEFLECTION AT 25,000 PSI STRESS	UNIFORM LOAD @ MAX. DEFLECTION = 1/240 SPAN	MAX. LOADING OF COLUMN
24"	**P 1000**	1690	.06	......	9,600
	P 1001	......	......	......	22,000
	P 1001 C41	......	......	......	38,000
	P 1001 3	......	......	......	27,700
	P 1004 A	......	......	......	32,400
30"	**P 1000**	1350	.09	......	8,900
	P 1001	3810	.05	......	21,600
	P 1001 C41	......	......	......	37,500
	P 1001 3	......	......	......	27,200
	P 1004 A	......	......	......	31,800
36"	**P 1000**	1130	.12	......	8,650
	P 1001	3180	.07	......	21,000
	P 1001 C41	......	......	......	37,000
	P 1001 3	......	......	......	26,200
	P 1004 A	......	......	......	31,400
42"	**P 1000**	970	.17	......	7,700
	P 1001	2720	.10	......	20,600
	P 1001 C41	5440	.10	......	36,500
	P 1001 3	......	......	......	25,300
	P 1004 A	......	......	......	30,500
48"	**P 1000**	850	.22	760	6,700
	P 1001	2380	.12	......	20,200
	P 1001 C41	4760	.12	......	36,000
	P 1001 3	......	......	......	24,000
	P 1004 A	......	......	......	29,500
60"	**P 1000**	680	.35	490	5,770
	P 1001	1910	.19	......	18,200
	P 1001 C41	3820	.19	......	34,500
	P 1001 3	4220	.13	......	21,500
	P 1004 A	5550	.13	......	27,200
72"	**P 1000**	560	.50	340	5,000
	P 1001	1590	.28	......	16,300
	P 1001 C41	3180	.28	......	32,500
	P 1001 3	3520	.18	......	18,200
	P 1004 A	4630	.19	......	24,400
84"	**P 1000**	480	.68	250	4,300
	P 1001	1360	.38	1250	14,800
	P 1001 C41	2720	.38	2500	30,500
	P 1001 3	3020	.25	......	14,400
	P 1004 A	3970	.25	......	21,300
96"	**P 1000**	420	.88	190	3,850
	P 1001	1190	.50	960	13,000
	P 1001 C41	2380	.50	1920	28,000
	P 1001 3	2640	.33	......	11,200
	P 1004 A	3470	.33	......	17,800
120"	**P 1000**	340	1.38	120	2,900
	P 1001	950	.78	610	7,700
	P 1001 C41	1900	.78	1220	22,000
	P 1001 3	2110	.51	2060	6,600
	P 1004 A	2780	.51	2670	11,000

ELEMENTS OF SECTION

Part No.	Wt./Ft. Lbs.	Area of Section Sq. In.	Axis 1-1 I In.^{4}	Axis 1-1 S In.^{3}	Axis 1-1 r In.	Axis 2-2 I In.^{4}	Axis 2-2 S In.^{3}	Axis 2-2 r In.
P 1000	1.90	.555	.186	.203	.579	.239	.294	.655
P 1003	3.35	.975	.325	.261	.577	.799	.400	.905
P 1001	3.80	1.110	.930	.572	.915	.478	.588	.656
P 1001 D3	5.70	1.665	1.302	.699	.884	1.450	.892	.933
P 1001 C3	5.70	1.665	1.413	.745	.921	1.521	.788	.956
P 1001 C41	7.60	2.220	1.860	1.145	.915	2.422	1.490	1.044
P 1001 3	5.70	1.665	3.132	1.267	1.371	.717	.882	.656
P 1004 A	6.70	1.950	4.062	1.666	1.443	1.107	1.207	.754

I — Moment of Inertia   S — Section Modulus   r — Radius of Gyration

Resistance to Slip — 1500 Lbs. per bolt
Pull Out Strength — 2000 Lbs. per bolt
Minimum Safety Factor of 3

CONVERSION FACTORS FOR BEAMS WITH VARIOUS STATIC LOADING CONDITIONS

SAFETY FACTORS

Loads in the load tables have a safety factor of approximately 2.4 based on the tensile or ultimate strength of the steel. This is adequate for many applications. However, certain codes require other safety factors and the loads, therefore, must be modified accordingly.

Check Table 2 for the application or safety factor and read the correction factor. Multiply load and deflection by the correction factor. This is the new design load and deflection.

TABLE 2

Safety Factor	Maximum Stress Lbs./Sq. In.	APPLICATION	Correction Factor
2.4	25,000	Displays Storage Racks	1.00
3	20,000	Mezzanines Structural Supports Electrical Supports	.80
4	15,000	Machine Frames	.60
5	12,000	Mechanical Supports for Pressure Piping	.48

Safety factor as used in this catalog is the ratio of the ultimate load or stress at failure to the design load or stress.

EXAMPLE I

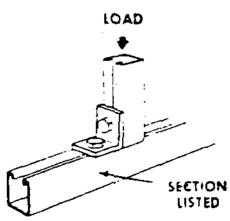
PROBLEM:
Determine beam size required to carry 900 pounds uniform with a 6'-0" span and a safety factor of 3.

SOLUTION:
A. Check load tables for size of members that will support 900# or more on a 6'-0" span and multiply by correction factor .80 (required for a safety factor of 3).
B. P2001 will carry 1100# X .80 = 880#
(not satisfactory)
C. P 1101 will carry 1230# X .80 = 984#
(satisfactory)
D. Use P1101, deflection will be .27 X .80 = .22.

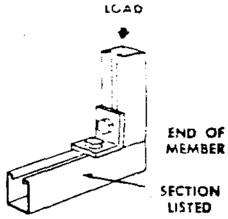
EXAMPLE II

PROBLEM:
Determine beam size required to support a 10" steam line weighing 740 pounds at the center of a 36" span.

SOLUTION:
A. Assume a member size of P1001 and read from load chart a uniform load of 3180#
B. Apply concentrated load factor from Table 2:
3180# X .50 = 1590#
C. Apply safety factor correction of .48.
1590# X .48 = 763#
D. P1001 beam will support 763# which exceeds the 740 pounds to be put on it.

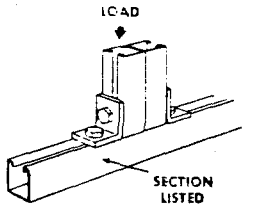


SECTION	RECOMMENDED LOAD IN LBS.*
P 1000	5000
P 1100	3500
P 2000	2000
P 3000	5000
P 3300	6000
P 4000	2200
P 4100	3400
P 5500	5000
P 5000	4000



SECTION	RECOMMENDED LOAD IN LBS.*
P 1000	3500
P 1100	2500
P 2000	1500
P 3000	3500
P 3300	4000
P 4000	1700
P 4100	2600
P 5500	3500
P 5000	2000

*Safety factor – 2½

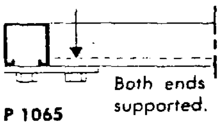


SECTION	RECOMMENDED LOAD IN LBS.*
P 1000	8000
P 1100	5500
P 2000	3000
P 3000	8000
P 3300	9000
P 4000	3500
P 4100	4800
P 5500	8000
P 5000	5500

DESIGN LOAD DATA FOR TYPICAL "UNISTRUT" CHANNEL CONNECTIONS

Safety factor = 2½ based on ultimate strength of connection.
Load diagrams indicate up to three design loads, one for 12 gauge sections (listed as P 1000), one for gauge sections (P 1100), and one for 16 gauge sect (P 2000).

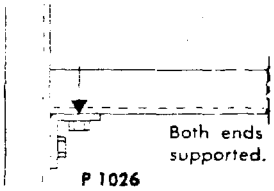
FLAT PLATE FITTINGS



P 1065

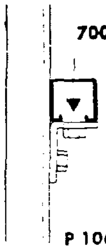
P 1000	1000 lbs.
P 1100	800 lbs.
P 2000	600 lbs.

NINETY DEGREE FITTINGS (When used in position shown)

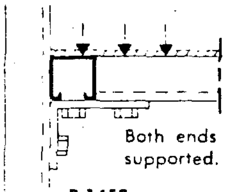


P 1026

P 1000	1500#
P 1100	1000#
P 2000	750#

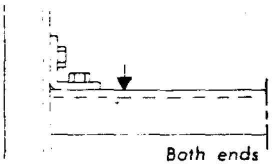


P 1068



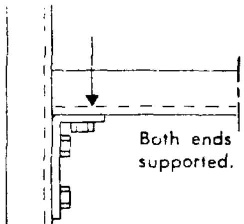
P 1458
P 1579

P 1000	150
P 1100	100
P 2000	100



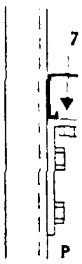
P 1026

P 1000	1000#
P 1100	650#
P 2000	500#

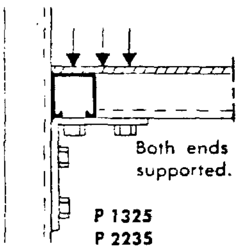


P 1346

P 1000	2000 lbs.
P 1100	1500 lbs.
P 2000	900 lbs.

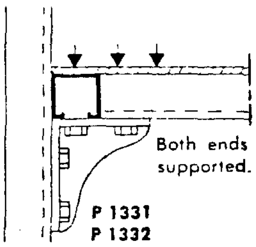


P



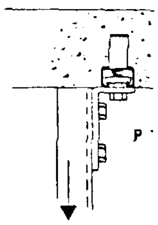
P 1325
P 2235

P 1000	2000 lbs.
P 1100	2000 lbs.
P 2000	1500 lbs.

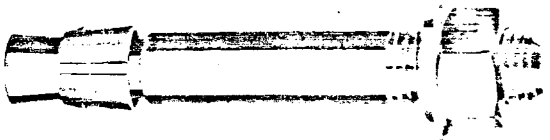


P 1331
P 1332

P 1000	3000 lbs.
P 1100	2000 lbs.
P 2000	1500 lbs.



HILTI KWIK-BOLT®



Hilti Kwik-Bolts are manufactured from high tensile steel, then zinc and chromate plated for extra protection against corrosion. Two independent spring steel wedges provide an extremely strong 360° anchorage when the Hilti Kwik-Bolt is tightened. Stud type Hilti Kwik-Bolts come complete with nut and washer. Bolt size is hole size. Reduce drilling time, drill strain, worker fatigue and bit costs. Sizes other than those listed are available on special order for virtually any fastening requirement.

Stud Anchors (including nut and washer)

Regular Kwik-Bolts

Catalog Number	Description	Size	Thread Length	Min. Embed.	Qty. per Box/Ctn.
5500004	14-158	¼" x 1⅝"	¾"	1⅛"	100/900
5500008	14-214	¼" x 2¼			100/900
5500012	14-3 *	¼" x 3"			100/600
• 5500026	38-218	⅜" x 2⅛"	⅞"	1⅝"	100/600
• 5500030	38-234	⅜" x 2¾"	1⅛"	—	100/600
• 5500034	38-312	⅜" x 3½"			100/400
• 5500038	38-5 *	⅜" x 5"			50/300
• 5500052	12-234	½" x 2¾"	1¼"	2¼"	50/300
• 5500056	12-334	½" x 3¾"			50/200
• 5500060	12-512	½" x 5½"			25/150
• 5500064	12-7 *	½" x 7"			25/100
• 5500074	58-312	⅝" x 3½"	1½"	2¾"	25/150
• 5500078	58-412	⅝" x 4½"			25/150
• 5500082	58-6	⅝" x 6"			25/100
• 5500084	58-812 *	⅝" x 8½"			25/75
• 5500096	34-414	¾" x 4¼"	1½"	3¼"	20/80
• 5500100	34-512	¾" x 5½"			20/80
• 5500104	34-7	¾" x 7"			10/40
• 5500108	34-812	¾" x 8½"			10/30
• 5500112	34-10 *	¾" x 10"			10/30
5500126	1-6	1" x 6"	2¼"	4½"	5/30
5500130	1-9	1" x 9"			5/15
5500134	1-12 *	1" x 12"			5/15
5600148	114-9	1¼" x 9"	3¼"	5½"	5/15
5500152	114-12 *	1¼" x 12"			5/15

Pullout and Shear Values (pounds)*

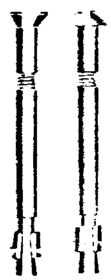
2000 psi Pullout	2000 psi Shear	4000 psi Pullout	4000 psi Shear	6000 psi Pullout	6000 psi Shear
2800	1653	3350	2612	3350	2389
3580	3792	4800	5419	5400	6266
9000	8897	12300	10232	15300	11522
9000	13378	17000	15437	21000	15437
16000	15195	23500	18466	23600	21009
18200	27355	27500	34491	35000	36394
26800	39843	40900	35680	44400	49596

• (UL) listed
766G
"Pipe Hangers"

*Average Pullout and Shear Values (lbs.) for maximum embedment of longest anchor shown. (Shear value is given across threaded section of bolt.) Maximum working loads should not exceed ¼ of the values for a specific anchor size. Actual factor of safety to be used depends on the application. For comprehensive independent laboratory pullout and shear data for each anchor size at various embedment depths, request Hilti bulletin TR 111 "Summary Report—Kwik-Bolt Testing Program." Holding values were obtained using Hilti carbide masonry drill bits. If other drilling systems are used, performance should be verified. Contact your Hilti Field Engineer for advice.

Post Nut Series

Size	Countersunk Cat. No.	Countersunk Desc	Roundhead Cat. No.	Roundhead Desc	Qty. per box/cart.
¼" x 2"	5500176	C 14-2	5500228	R 14-2	100/900
¼" x 3"	5500180	C 14-3	5500232	R 14-3	100/900
¼" x 4"	5500184	C 14-4	5500236	R 14-4	100/600
¼" x 5"	5500188	C 14-5	5500240	R 14-5	100/600
⅜" x 2¼"	5500202	C 38-214	5500254	R 38-214	100/600
⅜" x 3"	5500206	C 38-3	5500258	R 38-3	100/400
⅜" x 4"	5500210	C 38-4	5500262	R 38-4	50/300
⅜" x 5"	5500214	C 38-5	5500266	R 38-5	50/300



Post Nut Series Kwik-Bolt also available in 303 Stainless Steel with 304 Stainless Steel Heads

Super Kwik-Bolts

Super Kwik-Bolts, equipped with two sets of double-action spring steel wedges, are available on special order. Special order Kwik-Bolts can be produced for almost any anchoring requirement.

HKT 14 Tie Wire Anchor

Catalog No.	5500325
Length	2¼"
Head Diameter	⅜"
Min. Hole Depth	1½"
Bit Size	¼"

Installs with a claw hammer. 7/32" hole accepts large wire and chain hooks for suspended ceilings and fixtures.

Stainless Steel

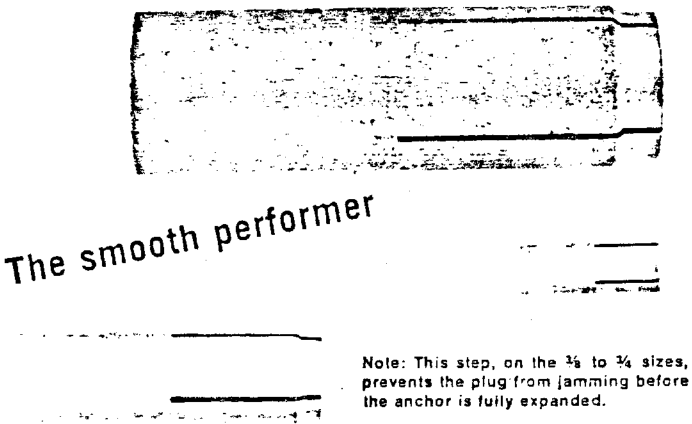
Catalog Number	Description	Size
5500005	SS14-158	¼" x 1⅝"
5500009	SS14-214	¼" x 2¼"
5500013	SS14-3	¼" x 3"
5500027	SS38-218	⅜" x 2⅛'
5500031	SS38-234	⅜" x 2¾"
5500035	SS38-312	⅜" x 3½"
5500039	SS38-5	⅜" x 5"
5500053	SS12-234	½" x 2¾"
5500057	SS12-334	½" x 3¾"
5500061	SS12-512	½" x 5½"
5500065	►SS12-7	½" x 7"
5500075	SS58-312	⅝" x 3½'
5500079	SS58-412	⅝" x 4½'
5500083	SS58-6	⅝" x 6"
	►SS58-812	⅝" x 8½"
5500097	SS34-414	¾" x 4¼"
5500101	SS34-512	¾" x 5½"
5500105	SS34-7	¾" x 7"
5500109	►SS34-812	¾" x 8½"

► Available upon special request with 2-3 weeks delivery.

Bolt: Type 303 Stainless Steel
Nuts and washers: Type 18-8 Stainless Steel
Wedges: Type 304 Stainless Steel

Prices and delivery on types other than Type 303 Stainless Steel Kwik-Bolt must be quoted on an individual basis.

HILTI HDI® Drop In Anchors



Pre-assembled two-piece design eliminates lost plugs, assures expansion even in soft or lightweight concrete.

Corrosion-resistant zinc plating meets or exceeds all applicable standards.

Bottom of hole not required to set anchor since internal plug is set from threaded end. Eliminates false anchoring and allows either flush or counter-sunk installation.

Available in all popular sizes

Catalog Number	Descrip-tion	Bolt Size	Hilti Drill Bit Dia.	Usable Thread Length	Qty. Per Box
5490000	HDI ¼	¼″	⅜″	7/16″	100
5490016	HDI ⅜*	⅜″	½″	⅝″	50
5490024	HDI ½*	½″	⅝″	11/16″	50
5490032	HDI ⅝*	⅝″	27/32″	⅞″	25
5490040	HDI ¾*	¾″	1″	1⅜″	25

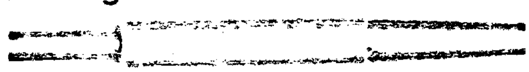
Average Pullout & Shear Strength Measurements

2000 PSI Concrete		4000 PSI Concrete		6000 PSI Concrete	
Pullout	Shear	Pullout	Shear	Pullout	Shear
1904	1738	2251	1781	3075	3050
3174	3970	4942	4225	5650	5900
3997	5873	6751	6224	10200	9350
5549	8883	9696	12205	10400	13600
8857	15195	16034	17609	16400	21200

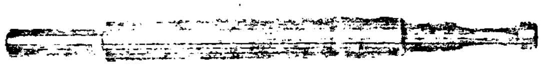
Made in U.S.A. UL listed 767G "Pipe Hangers"   Factory Mutual System Approved

NOTE: Maximum working loads should not exceed ¼ of the average values for a specific anchor size.
Actual factor of safety to be used depends on the application.
For comprehensive Independent Laboratory Pullout and Shear data for each anchor size, request HILTI bulletin TR110 "Summary Report—HILTI HDI Concrete Flush Anchors Test Program." Holding values were obtained using Hilti carbide masonry drill bits. If other drilling systems are used, performance should be verified. Contact your HILTI Field Engineer for advice.

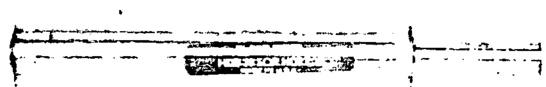
Setting Tools



TSD for Torna (use with TMHK Chisel Holder)



TESD for TE-17 (or use with TBA-17 in Torna or TBA-60 in TE-60)

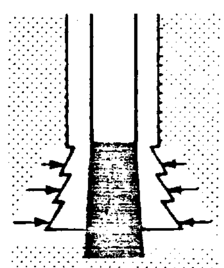


HSD (Hand Setting Tool)

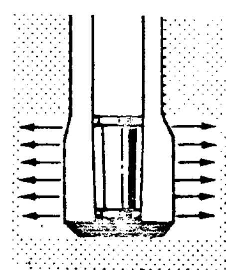
Machine Setting			Manual Setting	
Cat. No.	Description	for Anchor	Cat. No.	Description
5454500	TE-SD 6	HDI ¼	5454504	HSD 6
5454516	TE-SD 10	HDI ⅜	5454520	HSD 10
5454524	TE-SD 12	HDI ½	5454528	HSD 12
5455056	*TSD 16	HDI ⅝	5454536	HSD 16
		HDI ¾	5454540	HSD 20

*5065364 TMHK Chisel Holder Required

Maximum holding power through more uniform stress distribution in the surrounding concrete achieved by exclusive smooth design.



Conventional undercut expansion can cause stress concentrations in the concrete and cause premature failure



Special expansion provides uniform stress distribution and maximum friction against wall of hole

Performance characteristics of McCannalok valves

MAXIMUM RECOMMENDED PRESSURE DROP FOR USE WITH MANUAL LEVER HANDLE

	VALVE SIZE†			
	3	4	6	8
△P (PSI)	29	16	7	5
*F (GPM)	1182	1880	3310	4920
+V (FPS)	51.4	47.5	36.8	31.5
△P (PSI)	29	16	7	5
*F (GPM)	1007	1600	2820	4180
+V (FPS)	43.8	40.4	31.4	26.8
△P (PSI)	43	23	10	8
*F (GPM)	931	1450	2550	4020
+V (FPS)	40.5	36.6	28.4	25.8
△P (PSI)	60	33	14	11
*F (GPM)	798	1267	2200	3425
+V (FPS)	34.7	32.0	24.5	22.0
△P (PSI)	87	48	21	17
*F (GPM)	663	1052	1860	2950
+V (FPS)	28.8	26.6	20.7	18.9
△P (PSI)	157	88	40	32
*F (GPM)	552	882	1580	2490
+V (FPS)	24.0	22.3	17.6	16.0
△P (PSI)	267	154	73	57
*F (GPM)	376	690	1119	1740
+V (FPS)	16.3	17.4	12.4	11.2
△P (PSI)	455	278	140	105
*F (GPM)	192	334	616	943
+V (FPS)	8.35	8.43	6.85	6.04
△P (PSI)	740	518	287	200
*F (GPM)	44	80	159	226
+V (FPS)	1.99	2.02	1.77	1.45
△P (PSI)	740	740	350	325
*F (GPM)	0	0	0	0
+V (FPS)	0	0	0	0

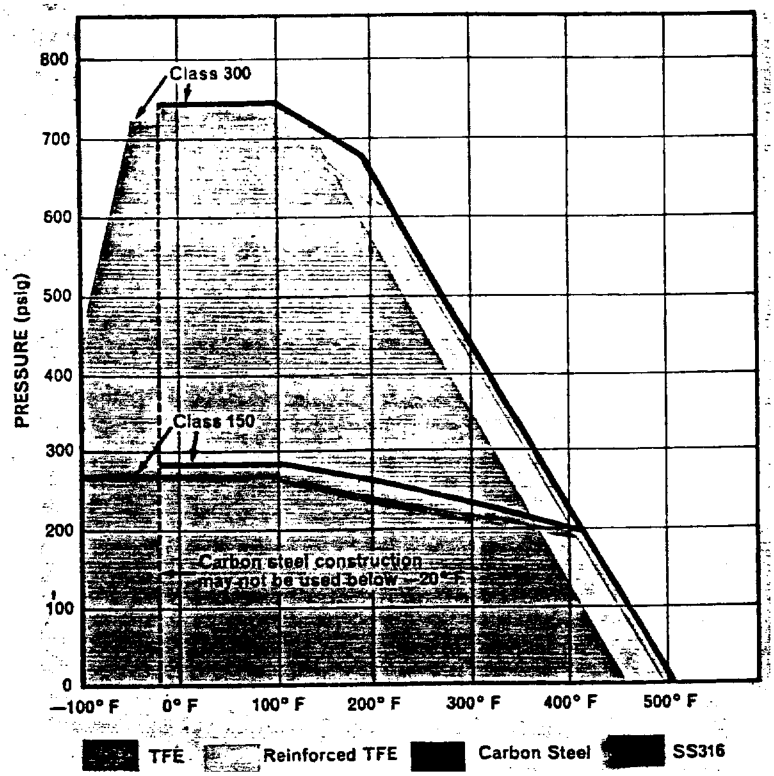
†When maximum working pressure will not exceed 50 psi, handles may be supplied for 10" valves. Consult factory.

Note: These values were calculated for the most unfavorable condition which occurs when the valve is installed with the seal retainer downstream.

* F = Flow rate (water) at indicated pressure drop.

+ V = Fluid velocity in Schedule 40 pipe at indicated flow rate.

PRESSURE/TEMPERATURE RATINGS PER ANSI B16.34-1977



WEIGHTS

	Valve Size (inches)											
Figure No.	3	4	6	8	10	12	14	16	18	20	24	30
L150	16	28	35	56	96	149	—	265	—	—	—	—
L151	25	33	53	72	121	188	230	360	440	560	985	1775
L300	16	30	40	55	100	155	—	—	—	—	—	—
L301	25	37	64	95	144	222	322	430	—	—	—	—

APPENDIX D

- Suction Header Tests -

A-Sector Suction Header Operational Tests, 1982

The 8" suction header tests initially developed from the need to know the peak pressures in the 8" header during full sector quenches. The peak pressure values could establish the need to utilize the auxiliary tunnel relief valves. These valves had been included in the initial header design to limit the pressure rise to 45-60 psig., but it was hoped that their use could be avoided both from an operational/safety point of view, and the cost to fabricate and install them. Previous testing at B12 had shown that peak pressures were at levels which would require the auxiliary tunnel relief valves, though some doubt still existed because of the physical differences between the B12 and the tunnel header. The A2 cryoloop 8" header was instrumented with strain gage pressure transducers, temperature sensing diodes, and a linear motion potentiometer to measure the dynamic pipe movement due to gas flow and the movement due to temperature. Their locations in the A2 cryoloop are shown on Figure 1. Note that the pressure transducers at 21-1 1Ø and 28-5 1Ø were installed on the magnet side of the Kautzky relief valve to monitor peak pressures in the magnet cryostats. It is known from B12 testing that the actual cryostat peak pressure is some 15 psi above the pressure as measured with the pressure transducers ahead of the Kautzky relief valves. Signals from all the transducers were routed to an eight channel chart recorder, typical output is shown in Figure 2.

The pressure data collected from full sector quenches with magnet currents of 1500, 2250, and 2600 A led to the conclusion that the vertical leg from the tunnel to the A2 relief valve was the major item limiting flow out of, and increasing the pressures in, the tunnel header. The data also indicated that proceeding to 4000 A full sector quenches would, in all probability, cause header pressures to exceed 100 psig design pressure limit. The pressure data quench current dependence decided the issue in favor of installing the 45 psig relief valves. Testing continued with the relief valves installed, in full sector quenches of 3000 and 3350 A. Projections from the data for these quenches indicated that the 45 psi tunnel relief valves would maintain peak header pressures below 90 psig at 4000 A, see Figure 3.

The 8" header motion transducer full sector quench data was reviewed for motion along the 200 feet length between expansion joints in the direction of the gas flow. No motion was seen during the pressure spike in the header on full sector quenches and only 1/4" of movement was detected on an asymmetrical one house quench. That quench of cells between A15 and A25 tested the pressure drop across the loop in the 8" header at the feedbox region. A pressure drop of greater than 10 psi would have required additional lateral restraint at the feedbox regions, but no measureable pressure drop was detected.

Temperature changes of the header during full sector quenches were observed to be less than 50°K. This corresponds to the extension of each expansion joint by approximately 1.25" well within the 2.0" working range, if the three expansion joints in a 400 foot section equally share the contraction of the header. This sharing of contraction was verified during Kautzky valve "opening verification" tests when Kautzky relief valves were opened allowing cold gas to enter the header. Measurements of each expansion joint when the header was cold and when it had warmed showed strokes of 1/4" to 1/2" with each expansion joint returning to its initial position within $\pm$ 1/8".

The temperature data showed that the header temperature dropped below 220°K during the 3350 A full sector quench. The cause was a stuck Kautzky relief valve adjacent to the temperature sensor. This situation is similar to initiating a quick cooldown through the 1ϕ spool relief valve. The header showed minimal movement in this occurrence.

Conclusions from these initial tests of the 8" header indicate that auxiliary tunnel relief valves will be required for full power operation of the Saver. These valves, set at 50 psig, will cause venting into the tunnel only for full sector quenches. The headers basic design features are adequate and anchors, braces, and brackets will be uniformly sized to allow 100 psig operation.

As a side note to these recent tests, preliminary cooldown tests on the 8" header were performed a year earlier. These earlier header tests monitored header movement as the liquid helium inventory of the A2 magnet string, approximately 700 liters, was dumped into the header through the cooldown valves located at each end of the magnet string. The time required to dump was approximately 35 minutes. During this time, each bellows was monitored visually for motion. The results verified that all bellows share pipe contraction in a given section and upon warming return to their initial state. Maximum bellows stroking was 1½". Another part of this test was to monitor header elevation to see if any vertical bowing of the header would occur due to differential contraction between the top and bottom of the pipe as first observed at B12. Bowing was observed at one end of the magnet string during the header cooldown. A 40-ft section of header lifted 2 in. immediately downstream of the cooldown valve. The opposite end of the string did not see this bowing. This is believed to be due to more turbulent flow and less stratification of the helium in the header. The region where the bowing was observed had no other flow than that from the cooldown valve. This was not true at the other cooldown valve region where both the refrigerator return flow and the warmed-up helium gas from the other cooldown valve passed through the header at this region on its way toward the compressor station. The magnitude of this bowing was not considered great enough to affect the header as bracket design can tolerate higher loading and flex hose vertical clearance is approximately 4 in. In addition, the probability of having the headers flow null point adjacent to the cooldown region should not be a usual occurrence.

In establishing an operating limit for the 8" header of 100 psig, consideration had to be given to the pressure drops in various locations under quench conditions as well as the peak pressures which generate gas flow. Aided by the A-Sector testing, the header was reviewed for operation. Table I lists principal elements in the tunnel 8" header installation and conclusions drawn from their analysis and review.

8" Header Element	Failure Mode	Failure Effect	Failure Pressure (Force)	Safety Factor	Maximum Working Pressure	Comments
I. Expansion Joint	Inelastic yield of convolutes	Loss of cycle life or leaks	200 psig	2 (with no squirm protection)	100 psig	Manufacturer states 120 psig max. working pressure
II. Flex Hose Assembly						
a. Braided Flex 2" & 3"	Rupture	Leaks	1000 psig & 1500 1500 psig	4	250 psig & 375 psig	
b. Spool Manifold	Rupture of alignment flex	Leaks	600 psig	4	150 psig	
c. Relief Valve Body	Fracture of flange lip	Leaks	12969 in-lb torque on flange	3 (with no rotation of valve body)	100 psig	Torque transmitted due to alignment flex.
III. 8" SCH 5 Pipe	Rupture	Leaks	1890 psig	5	378 psig	PER ANSI B 31.3
IV. 8" Tees & Elbows	Rupture	Leaks	---	---	158 psig	PER MSS SP43 fabricated welded tee
V. Feed Box Region						
a. Tie Bar	Yield of the bar	Excessive stroking of expansion joint and movement of pipe adjacent to feedcan	404 psig	4	101 psig	
b. Tie Bar Elbow Bracket	Deformation of elbow at bracket	Same as V.a.	468 psig	4	117 psig	
c. Lateral Support Structure	Slip of unistrut nuts	Same as V.a.	208 psi differential (6362 lbs)	4	52 psi differential	Assumes sharing of load on both sides of feed can thru tie bar
d. Tabs on 8" pipe vertical riser	Bending of tabs	Loading of adjacent expansion joints laterally until tie bar contacts feed can. Plastically deforms expansion joints. Possible leaks	306 psi differential	4	76 psi differential	
VI. Double Turn Around Region						
a. Anchor & Support Brackets	Slip of Header	Bending of cooldown piping. Possible leaks.	303 psi differential (9280 lbs)	3 (straps tightened to yield)	101 psi differential	Assumes sharing of load between 2 anchors & 2 supports
b. 6" Butterfly Valve	Rupture	Leaks	---	---	270 psi	Per manufacturer.
c. Fabricated Manifold 6" pipe	Rupture	Leaks	2234 psig	5	447 psig	Per ANSI B 31.3
VII. A12/F47 Ceiling Anchor	Anchor pull out	Excessive stroking of expansion joint possible leaks	496 psig	4	124 psig	
VIII. A12/F47 Wall Anchor	Same as VII	Same as VII	688 psig	4	172 psig	
IX. F47-3 Penetration Anchor	Pipe deformation	Excessive motion on expansion joint. Possible leaks.	468 psig	4	117 psig	
X. 11 & 49 End Anchor Assembly	Concrete anchor pull out	Excessive motion on expansion joint. Possible leaks.	660 psig	4	165 psig	
XI. Expansion Joint Guide Assembly	Bending of Guide	Excessive motion on expansion joint. Possible leaks.	1408 psig	4	352 psig	
XII. Pipe Support Assembly	Concrete anchor pullout	Excessive header movement & damage to flex hoses & any equipment underneath header.	4320 lbs. vertical 3040 lbs horizontal	4 4	(1080 lbs) vertical (960 lbs) horizontal	Supports are nominally every 10' or 100 lbs of header. 200' of header would have to lift to attain this loading vertically. Horizontal loading is nominally the rolling friction of rollers Less than 100 lbs.

FIG. 1

A2 8" HEADER
TEST LAYOUT

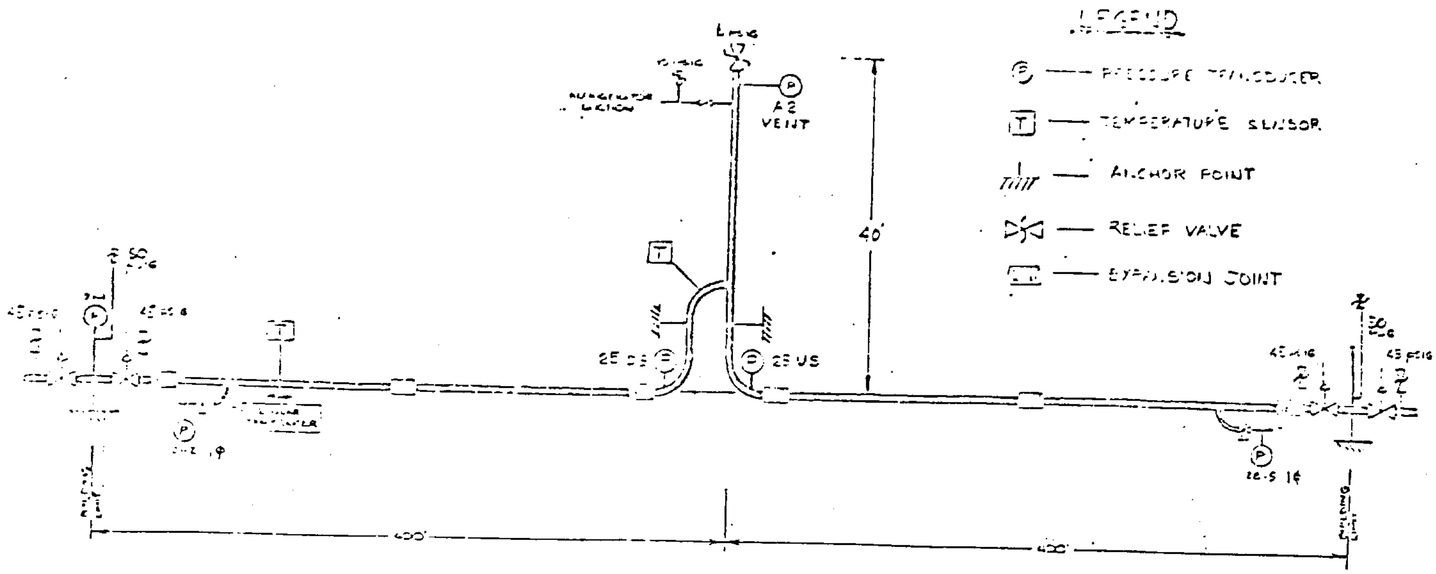
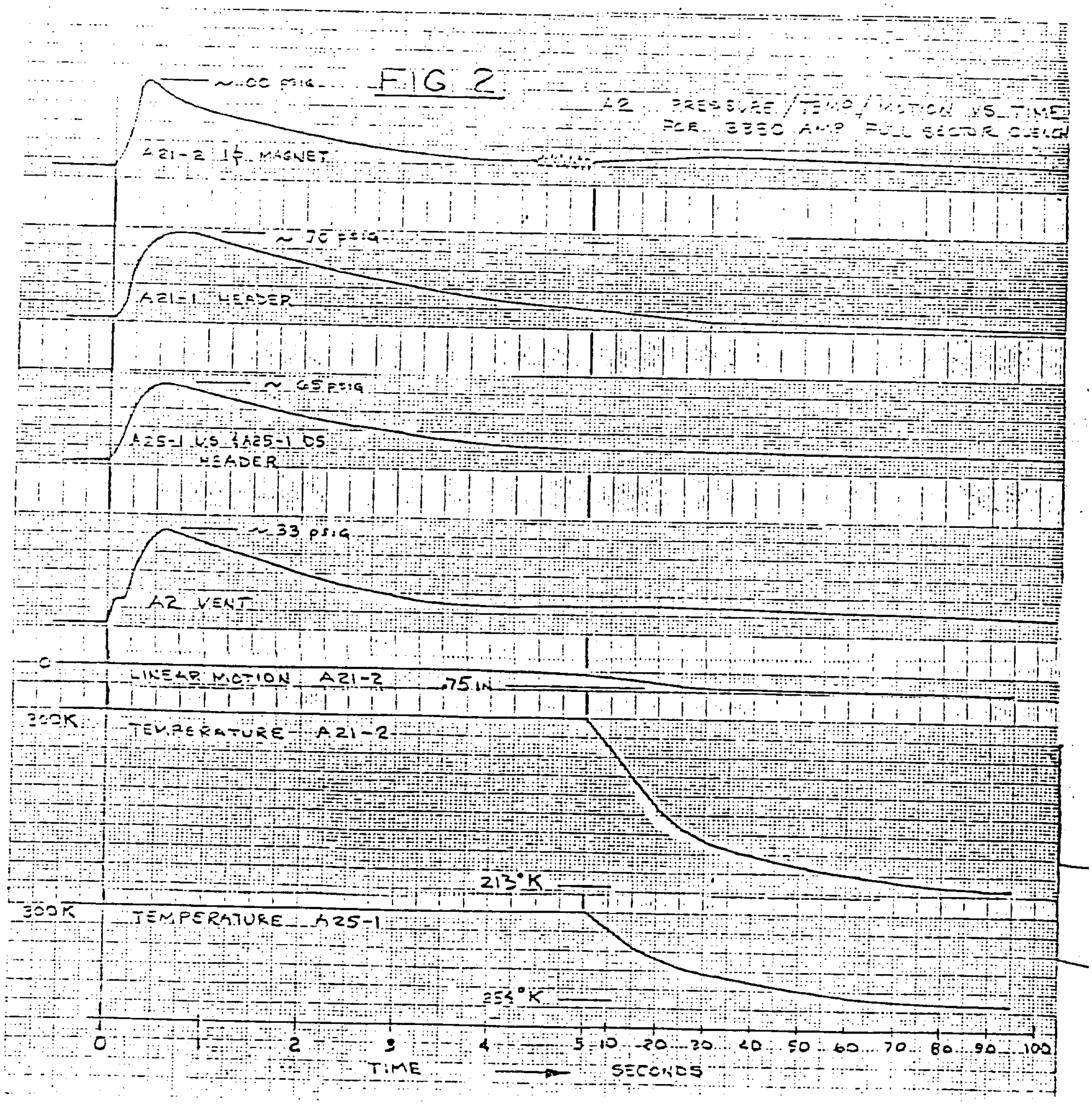
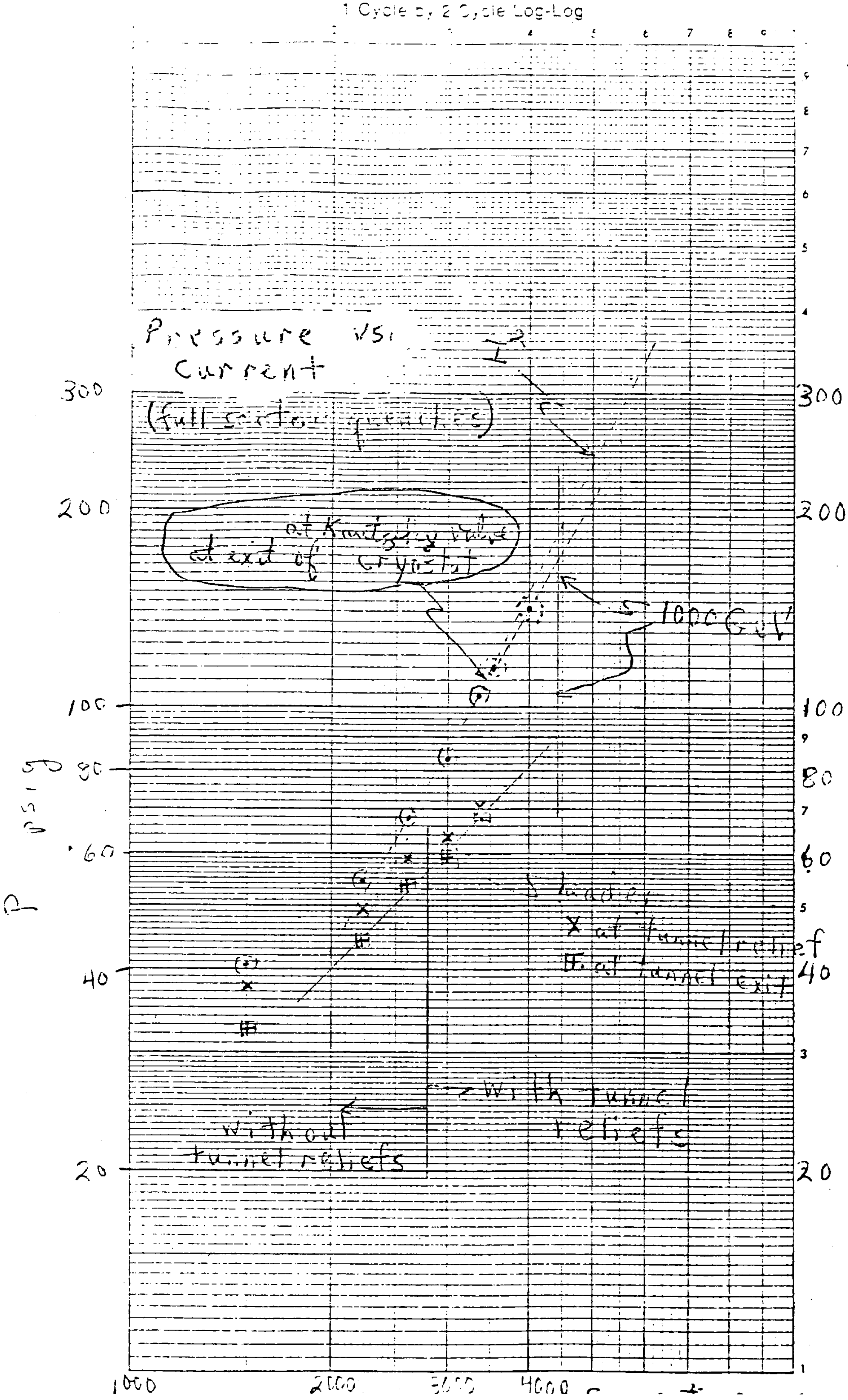


FIG 2




1 Cycle by 2 Cycle Log-Log
Pressure vs. Current
(full sector quenches)
at Kautzky valve
at exit of cryostat
I²
1000 GeV
X at tunnel relief
⊞ at tunnel exit
with tunnel reliefs
without tunnel reliefs
P psig
300
200
100
80
60
40
20
1000
2000
3000
4000

APPENDIX E

- A-Sector -

1. Quench log.

2. A-Sector header and single phase pressure data for A-Sector quenches other than full sector.

Quench log

date	time	current	which cells	# of Kautzky opened	leaks thru poppet? names	#	leak to tunnel names	#	replaced	#
2/12/82	2115	1000	A32, 34, 36, 38	50						
2/13/82	1527	1500	A26	14						
" 9/82	~1430	2225	whole sector	146	28-3, 29-4, 36-4	3	17-1Ø, 19-1Ø	2		
2/23/82	0030	1500	" "	146	A29-4, 36-5	2	14-1Ø	1	bolt OK 29-4, 36-5	2
2/23/82	?	2600	" "	146	19-5	1				
3/10/82	1520	1000	A28	14						
3/10/82	2000	1500	A19, 26	26						
3/10/82	1800	1500	A22, 26	26						
3/17/82	1430	3000	A19	14			19-1Ø	1	OK 19-1Ø	1
3/17/82	1936	3000	A24	14						
3/17/82	2033	3000	whole sector	146	18-4	1				
3/19/82	1425	3000	A17, 19, 22, 24	48						
3/23/82	~1600	3350	whole sector	146	14-5, 22-1Ø	2				
4/2/82	—	—							G10 nut 14-5, 22-1Ø 15-3 broken weld	1 1
4/15/82	—	—			32-1Ø	1			32-1Ø screw?	1
4/28/82	1650	2200	A25, 26	14					25-5 broken weld	1
4/29/82	1730	4000	A38, 37	14						
" "	2014	4000	all A2	50					26-1Ø leaking bellows	1
4/30/82	1505	4000	A17, 16	12						
5/8/82	1150	2250	A38, 37	14						
5/10/82	1346	4000	A19, 18	14						
5/10	2147	2500	all A1	48						
5/14/82	1450	4000	A19, 18	14	A19-4	1				
5/15/82	0033	3940	A15, 14	14						
"	1513	1315	whole sector	146					12-2, 14-4 cracked welds	2
5/16/82	0921	4000	all A1	48						
	1156	1900	A19	14						
	1907	3000	A19, A17, A13	40						
5/17/82	1717	4050	A19	14						
5/18/82	1750	4000	all A2	50					14-1Ø snap ring gone	1
5/21/82	1249	4000DC	A19	14					18-4 cracked weld	1
5/25/82	1600	4000	A26	14						
5/26/82	1145	4000	A26	14						
	1350	4000	A28	14						
	1516	4000	A32	14						
5/27/82	1040	4000	A13	14						
	1616	4000	A22	14						
5/28/82	1630	4000	A24	14						
6/2/82	1336	4000	A26	14						
6/2/83	1525	4000	A28	14						
				1582						

Quench log (cont'd)

date	time	current	cells	# Kautzky's opened	leaks thru poppet (names)	#	leaks to tunnel	#	replaced
6/3	0918	4000	A34	14					
	1155	"	A32	14					
	1330	"	A24	14					
	1500	"	A22	14					
	1700	"	A19	14					
6/4	0424	"	A24	14					
	1026	"	A15	14					
	1420	2600	A17	12					
	1555	4000	A38, 36	28					
6/5	1320	"	A24	14					
6/7	0954	"	A26	14					
	1322	"	A28	14					
	1458	"	A24	14					
	1710	"	A22	14					
	1922	3550	whole sector	146	A35-10, 20	2			
6/8	1800	1000	A19	14					
	1900	2200	A34	14					
	2130	4000	A19	14					
6/10	1410	4200	A19	14					weld cracked, 1
				1992		13		4	13

DISTRIBUTION OF QUENCi
by cell number

	5/17/82	6/15/82
A 13	9	11
15	9	11
17	11	13
19	16	22
22	9	14
24	9	16
26	11	17
28	8	13
32	7	10
34	7	10
36	7	9
38	9	11

Misek

6/15/82
CTM

Header & 1φ Pressure Data ($\Delta P = P_{max} - P_{initial}$)
A-Sector Quenches other than full sector Quenches

Date	6/10	6/10	6/7	6/7	6/7	6/7	6/5	5/27	5/26	5/18	3/19	3/17
Current	4200	4000	3550	4000	4000	4000	4000	4000	4000	4000	3000	3000
cells	A19	A19	whole sector*	A22	A24	A28	A24	A22	A28	all A2	A15 thru A24	A24
ΔP:												
A-2 vent	7.9	10.5	34.1		9.8		9.2		-	31.4	13.7	9.2
25 H - US	10.0	?	64.9		16.6		13.3			61.6	27.9	18.6
- DS	9.7	9.6	58.1		16.1		12.9			61.4	29.0	13.5
21-2 - 1φ			103.2	128.5			14.3	130.6		128.5	70.2	16.3
28-5 - 1φ			85.1			101.4	7.2		94.1	97.7		
21-1 header	20.3	17.5	49.3	23.1			16.9	?		49.3	55.4	14.1

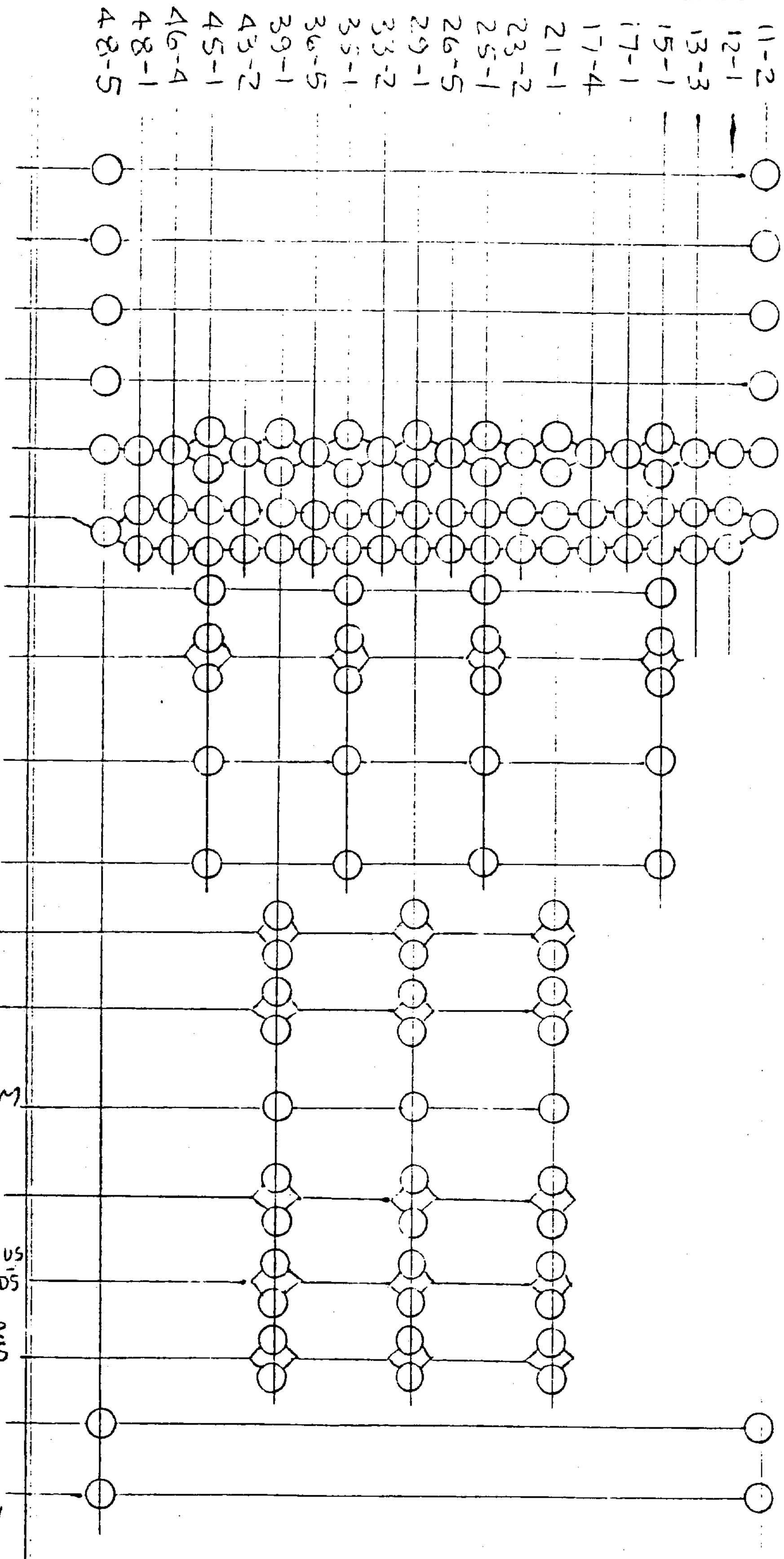
*but A19 went at 4000A 11 secs earlier and A17 9½ secs earlier

APPENDIX F

QC sheets and weld spec.

SECTOR ______ 8" HELIUM HEADER INSTALLATION CHECKOUT

ELEMENT	LOCATION



1. END ANCHOR WALL BRACKET
2. END ANCHOR PIPE MOUNT
3. END ANCHOR WALL STRAP
4. STA COOLDOWN PIPING
5. EXPANSION JOINT US/DS
6. EXP. JOINT GUIDE US/DS
7. FBA TIE BAR
8. FBA CHOCK BAR US/DS
9. FBA UNISTRUT WALL BRACKETS
10. FBA UNISTRUT DIAGONAL BRACE
11. DTA SUPPORTS US/DS
12. DTA ANCHOR US/DS
13. DTA 3/4" BALL VALVE & 50 PSI RELIEF ASSEM
14. DTA 6" ISOLATION VALVE & CONTROL US/DS
15. DTA 4" 50 PSI RELIEF US/DS
16. DTA COOLDOWN PIPING US/DS
17. 4" STACKS CAPPED
18. PIPE SUPPORTS @ PENETRATION REGION ON CEILING

DATE: ______
BY: ______

TRANSFER HALL
F- SECTOR
8" HELIUM HEADER INSTALLATION CHECKOUT
BY:

ELEMENT	LOCATION: F48-5	F48-3	F48-2	F47-5	F47-3	F47-2	F47-1	F46-5
ADDITIONAL ELEMENTS FOR F-SECTOR TRANSFER HALL REGION								
1. WALL ANCHOR							O	
2. CEILING ANCHOR							O	
3. WALL STRAP								O
4. PENETRATION ANCHOR ASSEM.					O			
5. EXPANSION JOINT					O			O
6. EXP. JOINT GUIDE					O			O
7. BRANCH HEADER ANCHOR						O		
8. BRANCH HEADER GUIDES		O	O	O	O			
9. STA COOLDOWN PIPING	O							
10. 4" STACK CAPPED					O			
11. CEILING SUPPORTS	O				O			

0 INSPECTION/TESTING

8.1 Fermilab representatives will monitor and inspect the installation as it proceeds. Any part of this specification not being followed will be reported to the Subcontractor for corrective action.

8.2 Areas that may require field discussions will be addressed immediately by the appropriate Fermilab personnel.

8.3 The final installation will be pressurized to 5 psig and all joints bubble checked for tightness by Fermilab personnel. Any leaks discovered, exclusive of existing work, will be repaired by the Subcontractor at his expense.

8.4 Any incorrect installation, poor workmanship, equipment loss or damage, material loss or damage, will be corrected by the Subcontractor at his expense.

9.0 QUALITY STANDARDS

9.1 All welding will conform to current ASME Boiler and Pressure Vessel Code latest revision and Petroleum Refinery Piping ANSIB31.3 latest edition and subsequent revisions.

9.2 Weld procedure shall demonstrate that all details are satisfactory for obtaining full penetration for all welds. This includes proper purge, proper heat, adequate shield gas, proper use of filler material, etc.

9.3 Welding equipment used in production shall be equivalent to that used for qualification as specified in 9.4 below.

9.4 All welders must be qualified by Fermilab tests. Passing these tests is a precondition to any welder performing services under this subcontract. The welding qualification tests specified in subparagraphs 9.4.1 through 9.4.3 below must be performed at the Fermilab Machine Shop under the supervision of welding shop personnel who will judge the samples.

9.4.1 "T" Weld Test

Weld two plates $4\frac{1}{2}$" long by 2" wide by .060" thick, made of 304 stainless steel to form a "T".

9.4.2 Lap Weld Test

Lap weld two plates 4" by 2" by 1/16" along the 4" length. This weld is to be a fuse weld using no welding rod. There should be good root penetration with no burn through.

9.4.3 Tube Butt Weld Test

Butt weld two 4" diameter, 6" long, .065" wall 300 series stainless steel tubes with 100% penetration. Tubes to be mounted stationary during welding with axis horizontal.

9.4.4 Criteria for passing Fermilab weld tests are:

9.4.4.1 Weld surface convex to slightly concave.

9.4.4.2 Proper technique.

9.4.4.3 Proper penetration control.

9.4.4.4 Proper gas coverage.

9.4.4.5 Proper heat.

9.4.4.6 Absolute leak tightness, tested with a mass spectrometer leak detector capable of detecting a minimum detectable leak of 2×10^{-9} std. cc/sec helium as defined in American Vacuum Society tentative Standard 2.1.

9.5 Only use austenitic stainless steel wire brushing or planishing to condition welds. Do not polish or remove surface weld material.

9.6 Final installation to be internally free of all chips, dirt, and weld slag.

APPENDIX G

1. Kautzky Valves: A - Sector Tests
2. Kautzky Valve replacement procedure

XIV. KAUTZKY VALVES: A-Sector Tests

C. T. Murphy

Introduction

The A-Sector Test afforded the opportunity to test a large number of the Mark III version of the Kautzky valve[3] under the duress of a small number of high-pressure quenches and true "field" conditions. This testing compliments the tests at MTF, where a few valves (about 15) have endured many hundreds of quenches, mostly in the shunted dump resistor mode, i.e., at moderately low pressures. The quantitative result of the failure statistics gathered is that a Mark III valve has a 1.2% probability of failing to close, after opening during a quench, in a manner that requires either immediate or next-down-day access to the tunnel. However, valve improvements already manufactured in the Mark IV version of the valve, magnet production improvements which reduce the number of screws, nuts, washers and G-10 pieces burped out through the valve by the magnets during a quench, and improved controls on the alignment and torque-down procedure on the manifold connecting the two spool piece valves to the 3" flex hose, should reduce this failure probability to about 0.2%. (See Fig. 1.)

The fact that flaws in both the Mark III valve and the early magnets installed in A-Sector required 13 valve changes finally forced us to invent, test, document, and train technicians to perform the sensitive procedure of changing a valve under "cold" (20°K) conditions. The procedure is quick, has been mastered by about six people, and declared adequately safe by Accelerator safety personnel. Failure on one front has led to success on a different front.

Valve Failure Statistics

The details of the failure statistics are as follows.[4] There were 146 valves in A-Sector mounted on the 1Ø or 2Ø relief ports which open during quenches above about 1000 amps in current. Each valve opened at least 9 times and at most 22 times, for a total of 1992 valve openings, during which 2Ø helium flowed violently through the valve. The total number of valve failures (including twice those valves which failed twice) was 24. These failures can be tabulated in two groups:

Failures which are already cured for the next run:

No. of Failures	Cause
7	Broken stem welds in valve
4	Leaks to tunnel through O-ring on spool piece 1Ø valve

Failures which will eventually be cured:

1	Poppet improperly secured to foot
9	Valve cured without replacement by torching and "popping"
3	Valves removed after failure to reset after torching and popping, had magnet hardware imbedded in poppet

Discussion

These failures warrant some discussion. The first one, "broken stem welds", was anticipated and already cured at the design and fabrication level before the A-Sector tests, but we had to use existing, obsolete valve actuators. When a stem weld failed, the valve failed <u>unsafe</u> (closed, will not open during a quench). This failure was detected by a sudden increase in the flow from the control pressure bottles[1] (a leak of warm helium into the 1Ø system through the broken weld.). In the Mark IV version currently being assembled, weld failures can still occur, but the valve will fail safe (i.e., open).

The second failure mode, "leaks to the tunnel through O-ring on the spool piece 1Ø valve" were clearly a result of very hasty installation of valves last summer. The leaking joints were found to have Marmon clamps which were extremely loose, and in all four instances, the leaking joint was the 1Ø joint between the spool piece flange and the Kautzky valve. The two Kautzky valves on the spool piece (1Ø, 2Ø relief) connect to a common manifold and must be properly aligned before final torquing of the Marmon clamps. This alignment and torquing procedure will be more carefully controlled in E and F Sectors hereafter.

Nine valve failures to reseat with leaks through the poppet were solved by a combination of thawing the frost with propane torches and "popping" the valves by removing momentarily the control pressure line. "Popping" the valve open was intended to flush out removable debris trapped between the poppet and the aluminum body, if trapped debris was the cause of the valve not fully closing. Another possible cause of a valve failing to close fully when cold is called the "alignment problem". If the actuator shaft is not concentric with the body seat by an amount between about 0.020" and 0.030", the valve will seal well at room temperature (because of the loose fit between the polyethylene poppet and the steel foot), but will not seat well cold because the loose fit has become a tight fit. By torching the aluminum body until it is a little above room temperature, and hopefully warming the poppet, then "popping" the valve open once gives it a chance to reseat warm.

Of the nine failures, at least four were definitely caused by trapped debris. This is known because later inspection of the poppets showed clear "footprints" of indentifiable objects on the poppet: 6-32 threads or a star washer. At least one was clearly a misalignment problem: the valve reseated suddenly while we were torching it, with an audible "crack". The other four instances can be attributed to either problem. Two of the poppets had definite notches on the seating surface (but so do most valves which come back from MTF after hundreds of cycles, none of which failed to reseat after a quench). The other two poppets appeared quite unscarred.

Three valves failed to close after torching and popping and had to be replaced immediately. All three had loose magnet hardware firmly wedged between the poppet and the body: a piece of G-10, a 6-32 screw, and a 6-32 nut. This hardware was used prior to magnet number 528 in the instrumentation lead tie-down system. Since then this hardware has been either riveted, "staked", or secured with Locktite 404 (see memo from J. Carson to T. Murphy, dated April 14, 1982). However, most of the magnets in A-Sector have serial numbers below 528.

By way of contrast, 16 valves of this same version have endured a total 3800 quenches at MTF without a single failure of this kind - failure to reseat after a quench. At MTF, the magnets all had serial numbers greater than 528. Both the MTF experience and our own data (indicating that as many as eight of the nine failures <u>might</u> be the result of trapped debris) suggest that the failure-to-close problem will eventually go away in the tunnel.

The most troubling failure occurred only once. A poppet became detached from the actuator foot, failing unsafe (i.e., the valve remained closed during several quenches). Post-mortem analysis by Tom Peterson revealed that the snap-ring had not been properly set in the groove of the poppet, came loose, and after being once squashed into the poppet (its footprint was clearly identifiable), was flushed into the header. The groove in the poppet showed no signs of having broken away, which led to the conclusion that the snap-ring was never set fully in the groove. This failure is troubling because it was discovered only by chance. It was discovered while searching for a broken stem weld, and was discovered because the valve failed to open when the control pressure was removed. We know that it had been failing to open for several weeks because we had noticed that the actuator of this valve was badly "domed", a result of the extra high pressures from the unrelieved magent. This failure points out the need to install Klixons on each valve - as planned - to prove in each quench that every Kautzky valve opened.

Conclusions

In Fig. 2, the valve failure rate is plotted as a function of cumulative valve openings. The graph suggests that the rate of failure was declining towards the end of the run. If this decline is real, it would confirm Koepke's qualitative observation at B-12 that most of the loose debris in magnets is blown out during the first ten or so quenches.

By way of conclusion, let us make a somewhat speculative projection of the failure rate expected in the next cryogenic run, the E-F Sector Test. Weld stem failures will not occur, nor will leaks through O-rings to the tunnel. Let us assume that failures to reseat because of trapped debris will be reduced by a factor of three as a result of improved magnets, and that the valve alignment problem is eliminated (as we currently believe). The resulting failure rate would then be about 4/1992 = 0.2% per valve opening, or 2.8% per full-cell quench. If there are ten full-cell quenches per day, one would then expect to have to service a Kautzky valve about every four days.

Procedures For Changing Valves

Procedures and special tools were invented (see ref. 2) during the A-Sector run which permit changing Kautzky valves when the 1Ø system is at 20°K or warmer and 2 1/2 psig or lower. The main hazards of the procedure are the momentary cloud of cold gas emitted from the 1Ø relief port while it is open and the possibility of emptying the warm header helium into the tunnel if it is not promptly capped. The job has been classified as an ODH class 2 job. At the moment, the job requires two trained technicians who do all the work and two observers who are needed for communication with the Tevatron console by walkie-talkie relay. A valve change takes a total access time of about 1 1/2 hours, but only 20 minutes for the actual changing procedure.

References

1. C. T. Murphy, "Doubler Kautzky Valve Supply Manifold Adjustment and Bottle Changing", Operations Bulletin No. 877, April 9, 1982.
2. C. T. Murphy, "Rules and Procedure for Kautzky Valve Change in Tunnel under Cryogenic Conditions", to be published.
3. "The Kautzky Valve", Fermilab Reports, June, 1982.
4. C. T. Murphy, "Kautzky Valve Problems in Tunnel", bulletins no. 1 through 6.

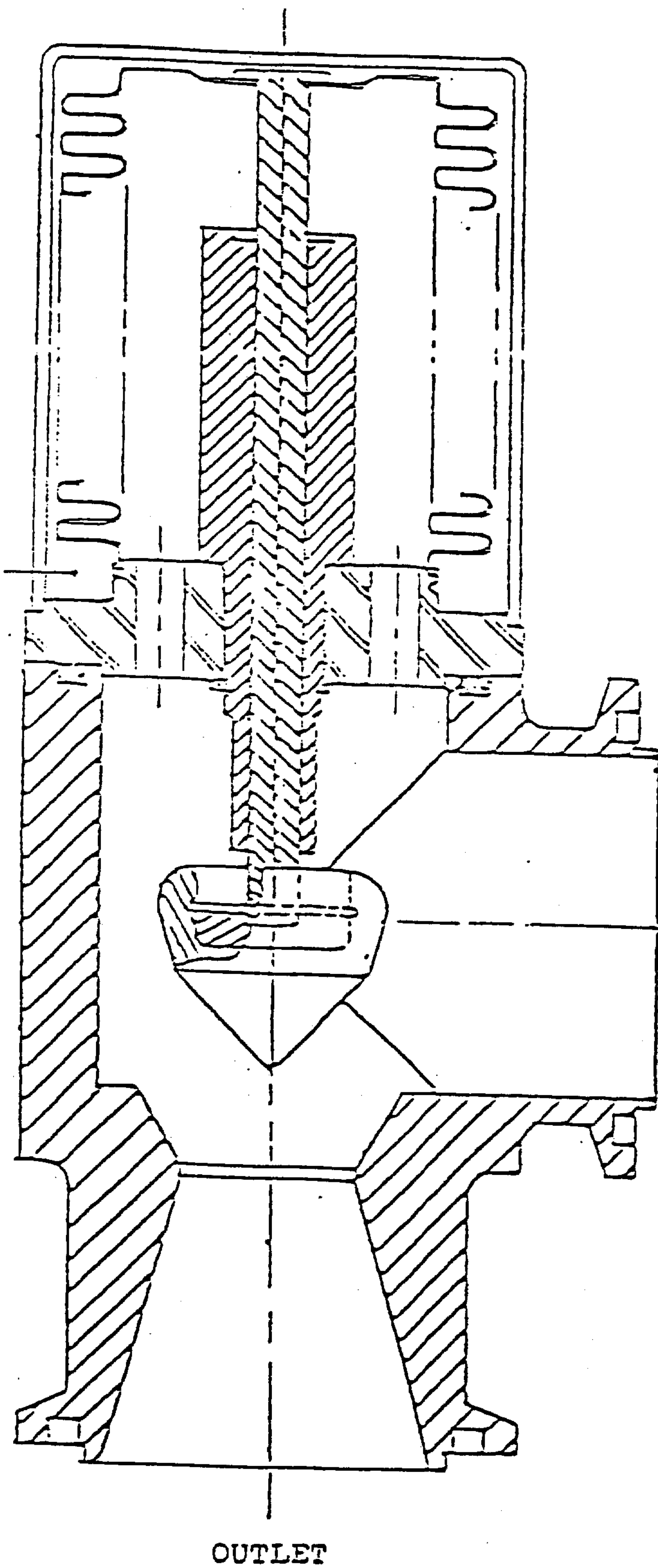
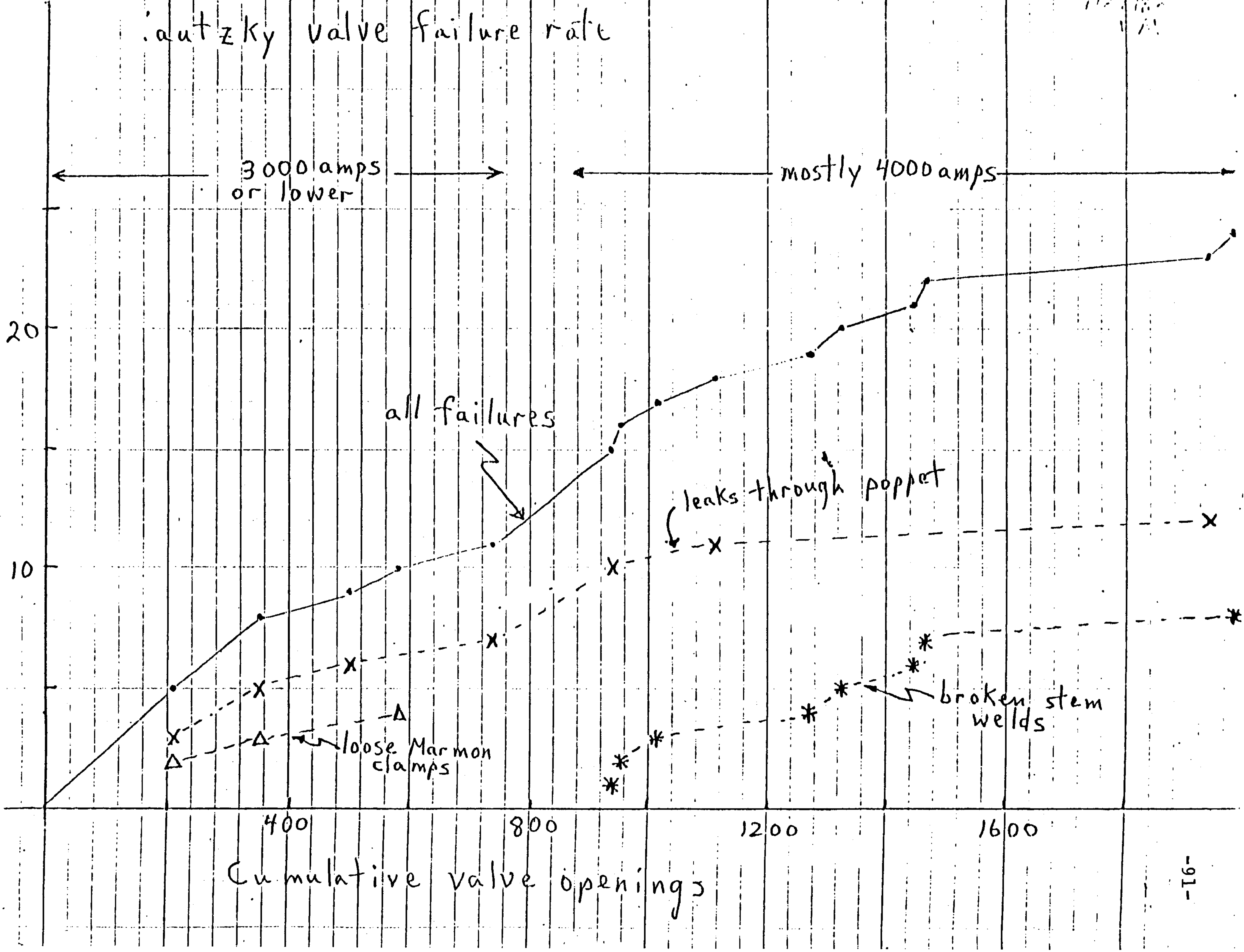


Figure 1. Kautzky valve.


.autzky valve failure rate
3000 amps
or lower
mostly 4000 amps
20
10
all failures
leaks through poppet
loose Marmon
clamps
broken stem
welds
400
800
1200
1600
Cumulative valve openings

Fermilab

November 22, 1982
C.T.Murphy

KAUTZKY VALVE REPLACEMENT PROCEDURE UNDER CRYOGENIC CONDITIONS

Necessary Personnel

The three-man team actually changing the valve must be led by a Cryogenic Expert or a Senior Cryogenic Operator who has participated in a cold valve change at least once and who is capable of operating and reading the refrigerator locally, and is on the approved list. The second must be a Cryogenic Operator, Level 2 or higher, who has participated in a cold valve change as an observer and is on the approved list. The third team member can be a novice for whom this participation is regarded as a training session. He can lend a hand if anything goes wrong.

The above three-man team must be accompanied by a safety officer familiar with this procedure whose responsibilities are to monitor oxygen, double-check that the required safety apparatus is in use, and rescue assistance in the event of an injury or emergency. He has the authority to take charge of aborting the mission if in his judgment an emergency situation has developed. In addition, there should be a fifth person present to maintain communications with the Doubler console in MCR by telephone or walkie-talkie and who can call for additional help if an emergency develops. This person should be familiar with, but not expert in, the cryogenic system and terminology.

Necessary System Conditions

The cryogenic team leader must personally verify that the following system conditions have been achieved:

A. Helium Valve Change -

1. The bypass valve (EVBY) must be put in local control and opened 100%.
2. The upstream and downstream 1Ø system must be brought to a pressure of less than 2-1/2 psig and a temperature of greater than 20°K. These limits may be changed with the approval of the Cryogenic Safety Officer (C.Bonham or his designate) as we gain experience.
3. The suction (header) pressure must be maintained at 2-1/2 psig or less. Since this pressure cannot be put in local control, communication with the Doubler console is necessary at certain points in the procedure to confirm this pressure.
4. The supply valve to CHL (EVLH), the upstairs JT (EVJT), and the high pressure helium supply valve to the refrigerator (MV101H) must be closed and put in local control.
5. The two tunnel JT valves (EVUH, EVDH) must be open and put in local control.

B. Nitrogen Valve Change -

1. The LN2 supply valve must have been closed for two (2) hours and put in local control. (EVUN or EVDN.)

2. The LN2 pressure must be less than 3 psig. (PI-21 or PI-22.)

Necessary Safety Equipment

All persons entering the tunnel will be equipped with personal oxygen monitors and escape packs, as usual.

The three-man cryogenic team will be equipped with lined leather gloves, full face masks of the type with fiberglass chin guards, and two layers of arm and check protection (e.g., shirt and light coat, both with full arms, of any material). The face masks must be in place prior to any anticipated venting of warm or cold gas. The lined leather gloves may be removed only when cold gas is not being vented into the tunnel.

Necessary Briefing

The three-man cryogenic team will "talk through" the latest version of the valve changing procedure in the presence of the safety officer prior to entering the tunnel, in order to assure that everyone involved is somewhat preprogrammed to do his job without discussion, and to clarify each person's role and tasks.

mhr

APPENDIX A

COLD KAUTZKY VALVE REPLACEMENT PROCEDURE FOR DIPOLES AND NITROGEN

Prep Work: New valve has 15 psig temporary pressure line to actuator with ball valve in pressure line

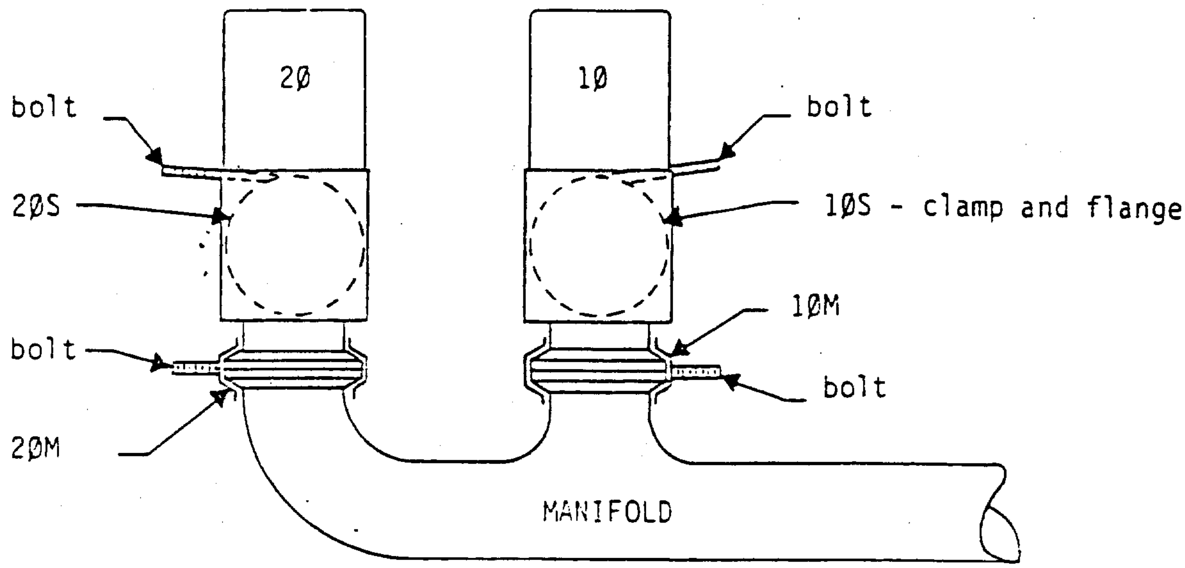
	Man A	Man B
0.	Connect portable bottle to new Kautzky valve.	
1.	Hold old valve; press in hard.	Undo Marmon clamp.
2.		Drop clamp, grab plunger.
3.*	Remove old valve (still pressurized, still attached to flex hose).	Insert plunger into magnet.
4.	Cap magnet side of old K-valve and attach Marmon clamp (5 lbs force to fight).	
5.	Grasp new K-valve and position self to insert; check that poppet is open.	
6.*	Insert new K-valve to magnet; push hard.	Remove plunger.
7.		Pressurize new K-valve (close poppet). Install <u>new</u> Marmon clamp.
8.		Tighten Marmon clamp nut on magnet-K interface, 80 in.-lbs torque.
9.	Thaw new Kautzky with propane torch.	
10.	Grasp permanent flex hose and old valve.	Disconnect permanent flex hose from old K-valve.
11.*	Move flex hose to new K-valve.	Marmon clamp flex hose to new K-valve.
12.	Remove copper pressure line from old K-valve and thumb shut.	Remove temporary pressure line from new K-valve and valve off.
13.	Insert copper line to new K-valve.	Thread and tighten Swagelock nut on copper line to new K-valve.
14	Snoop Swagelock joint just installed.	
15.	Reduce control pressure to 30 psig if necessary.	
16.	Raise 1Ø pressure to 10 psi, inspect new valve for leaks.	

*During these steps, helium is escaping into the tunnel.

Rev. 4/19/82

APPENDIX B

COLD KAUTZKY VALVE REPLACEMENT PROCEDURE FOR 1Ø ON SPOOL PIECE



	Man A	Man B
1.	Loosen clamp 2ØS until it can rotate (slide on O-ring).	Attach new valve to portable gas bottle. Do not pressurize. Attach and pressurize portable bottle to 2Ø valve.
2.	Remove clamp 1ØM	Push up on underside of manifold under 1Ø valve.
3.	Slip wedge cap onto manifold flange 1ØM.	Pull down on manifold, rotating about clamp 2ØS.
4.	Hold and push 1Ø valve body towards spool.	Remove clamp 1ØS. Pick up plunger.
5.	Remove Kautzky 1Ø valve.	Insert plunger into spool.
6.	Clean O-ring seat on spool piece flange 1ØS.	↓
7.	Insert new K-valve and push hard.	Remove plunger.
8.	↓	Pressurize new K-valve with portable bas bottle.
9.	↓	Install* new Marmon clamp at 1ØS; tighten loosely (seal, but can still slide).
10.	Loosen clamp 2ØM until it slides on O-ring (if necessary for realignment).	
11.	Remove wedge cap from 1ØM.	Push up on manifold to seal the joint at 1ØM.
12.	Install* Marmon clamp on 1ØM. Tighten clamp loosely.	↓

(over)

Man A	Man B
13. Torque all clamps to 80 in.-lbs in the following order: 1ØS, 2ØS, 2ØM, 1ØM.	Reconnect copper pressure lines to the two valves. <u>Careful</u>: the two copper lines are <u>not</u> interchangeable. The copper line to the 1Ø goes through a solenoid valve.
14. Snoop both Swagelock joints just installed.	
15. Reduce control pressure to 30 psig if necessary.	
16. Raise 1Ø pressure to 10 psig, inspect both valves for leaks.	

*The direction in which the protruding bolt of the clamp points is important; see Fig. 1. On flanges 2ØM and 1ØM, the bolt should be on the <u>spool</u> side of the valve (not the aisle side).

Fermilab

February 28, 1983

TO: J.R. Orr

FROM: R.W. Fast *RWFast*

SUBJECT: Operation of Sections E & F above 2 kA

We have reviewed your transmittal of February 25, the "Murphy-Misek Report" and have the following comments:

a) The authors consistently state the the 8" parallel-plate relief device at the compressor is set to crack at 12 psig (e.g., page 1). If the relief valve in mind is SV-003-H, the cracking pressure given in other documents and flow sheets is 6 or 7 psig and never 12 psig.

b) There appears to be a significant typographical error on page 13, where the probability is given as 1/77, which should probably be 1/177.

Aside from these items we find the report to be very thorough and have the following recommendations:

1) We urge that the question of a failed regulator be pursued (page 14).

2) We are glad for your concern regarding stuck Kautsky valves, but we do not feel that we are qualified to recommend a specific scheme to determine if the valves are operational.

3) We question whether the provisions and recommendations of the report have been fully implemented in Sectors E and F. Specifically, in page 15 it is said that snow protection have been installed, yet our on-site inspection revealed that they had not. We also wonder about the various brackets.

4) We recommend that Appendix A be completed.

In summary, we feel that we can now recommend that you authorize the operation of Sectors E and F to full current, with the above six items corrected and/or implemented in the near future.

RF/tg

Fermilab

March 9, 1983

To: Ron Fast

From: Rich Orr

Subject: OPERATION OF E AND F SECTORS ABOVE 2kA (THE "MURPHY-MISEK REPORT" - YOUR MEMO OF FEBRUARY 28, 1983)

Following is our response to the questions/comments posed in your memo of February 28, 1983:

a) The valves referenced in the "Murphy-Misek Report" are SV-400-H and SV-403-H which are set at 12 psig.

b) A revised page 13 is attached on which "1/77" has been corrected to "1/177."

1) The regulator which supplies control pressure gas to the Kautzky relief valves is a Victor Model VTS-450B. The only failure mode conceivable is the deterioration of the elastomer seals in the two stages of regulation. The worst-case situation would be both seals vanishing simultaneously; this is highly improbable. Slow deterioration of one or both seals is, however, a more likely occurrence; this would be discernible since there would be a decreasing ability to regulate to any pressure.

A test was performed to confirm the ability of 50-psig relief valves to handle the gas flow from a failed regulator. A spare control gas panel was connected to a high-pressure helium bottle as is typical in a normal installation. Since the Kautzky relief valves and copper lines would not significantly affect the test, they were excluded from the setup. The regulator was then failed intentionally by the removal of the elastomer seal from both the first and second stages of the regulator. The regulator flow was then limited by metal orifices of the valves.

The results of the test were as follows:

Fermilab

March 23, 1983

TO: Ron Fast

FROM: R. Orr

SUBJECT: Appendix A, Safety Analysis of the 8" Low Pressure Helium Header System

Attached are four copies of Appendix A (header calculations) to the Safety Analysis of the 8" Low Pressure Helium Header System paper which was transmitted to you by my memo of February 25, 1983.

RO/ew

cc: W. Fowler
T. Murphy
J. Misek
C. Vanecek

Fermilab

1-2.10300

February 25, 1983

To: Ron Fast

From: Rich Orr

Subject: SAFETY ANALYSIS OF THE 8" LOW-PRESSURE HELIUM HEADER SYSTEM FOR THE ENERGY SAVER

Enclosed are four copies of the subject report as requested in your memo of November 19, 1982, (Additional Documentation Needed for Phase 4 and 5 Approvals). Appendix A, Header Calculations, is not included at this time since it is not yet in a completed form. It will be transmitted to you by March 4, 1983.

cc: T. Murphy
Sector Cryogenic Safety Review Panel Members, w/encl.
J. Misek
L. Read